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TROPICAL AGRICULTURE

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Editorial

All who have been connected with the Imperial College of Tropical Agriculture will welcome the news that an I.C.T.A. Association has been formed. Mr C. Holman B. Williams has been elected President.

Membership is open to all past students who have spent at least one academic year at the College and to past and present members of the senior staff. The subscription for members resident in Trinidad and Tobago is $5.00 (W.I.) per annum and for those resident elsewhere $1.00 (W.I.) per annum. Subscriptions should be sent to the Honorary Treasurer, Mr E. F. Iton, I.C.T.A., St Augustine, Trinidad, W.I.

It is hoped that local branch associations will be formed in various parts of the Commonwealth and that in due course the parent body in Trinidad will be in a position to circulate news of their activities, etc.

For further information, enquiries may be addressed to the Honorary Secretary, Mr V. O. Ferrer, Department of Agriculture, Port of Spain, Trinidad, W.I.

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Soil Drying and Soil Fertility

H. F. Birch

East African Agriculture and Forestry Research Organisation, Kikuyu, Kenya

The effect of soil drying and burning on soil fertility has been recognized for some time. Only recently, however, has the underlying mechanism been studied in sufficient detail to enable a hypothesis to be formulated that puts the drying effect on a predictable basis, especially with regard to soil nitrogen. It is, therefore, of interest to summarize some of the observations in the literature on soil-drying and follow this with a brief account of current work which unifies these observations and shows how important the drying effect is in agriculture and how it may be applied in practice.

During the early part of the twentieth century a considerable amount of work was done on the influence of soil drying on soil fertility culminating in the papers by Gustafson (1922) and Lebedjantzev (1924). Thereafter interest in the subject appeared to lapse until fairly recently. Gustafson, in his paper on the effect of drying soils on the water-soluble constituents, gives a very comprehensive review of the literature on soil drying up to 1922 and no attempt has been made to reproduce his bibliography here. It may, however, be noted that soil burning is mentioned by Virgil in the Georgics and that this practice still plays an important part in various agricultural systems such as the *chitemene* system in Rhodesia and the ' Rab ' system in rice growing.

While Gustafson was primarily concerned with the physicochemical aspect of soil drying in relation to the solubility of inorganic salts, Lebedjantzev was more concerned with the effect of soil drying on yield and some interesting and rather spectacular results were obtained. Thus, millet yields in a soil that had been air-dried and then remoistened were, on an average, 45 per cent greater than those in a soil which had not been dried but was otherwise identical. Yield increases of up to 125 per cent were recorded in extreme instances, and large yield increases were also found for other crops. The effect of drying on yield was found to be greatest with uncultivated soils, less with soils under perennial grass and still less with soils subjected to ordinary methods of tillage. The application of manure and phosphoric acid was found to increase the effect of drying. When yield increases due to drying were expressed as a percentage of the yielding capacity of the moist soil it was found that the less fertile soils responded better to drying.

With regard to the effect of drying on various plants Lebedjantzev found that meadow plants responded more than leguminous and field crops and these, in turn, more than root crops and tubers. In general the greatest response occurred with plants which, under natural conditions, thrive in soils not subjected to the drying influence in tillage operations (meadows) and the least response was obtained with cultivated plants exposed to the greatest artificial drying by cultivation in the row. The cultivated soils

had to be dried down to a 6 per cent moisture content for the drying effect to occur, while the corresponding value for uncultivated soils was 14 per cent. In testing the drying effect on soil from different horizons (yield increases being expressed as a percentage of the yield on the moist samples) the maximum effect for a deep black soil was found at the 20 to 40 and 40 to 60 cm depths, i.e. where marked drying under field conditions does not occur. Lebedjantzev concluded that during the process of drying chemical changes take place in the soil causing an increase in the solubility of organic substances and an enrichment with nitrogen and phosphorus. In addition to dehydration, temperature was also considered to be an operative factor in these changes.

Lebedjantzev's work has been discussed at some length because it shows the importance of the drying effect on yield and the conditions required for the effect to operate. Also it is interesting to relate his findings with recent work, discussed later, on the underlying cause of the drying effect.

Steenkamp (1928) studied the effect of dehydration of soils on their colloid constituents and his paper includes a brief review of the literature on this subject. He considers that the drying of a soil is a natural factor in transforming plant nutrition substances from a potential to an active form and that flocculation of the colloids (through drying) also leads to increased fertility due to improved physical conditions. He states that an increase in nitrogen and phosphorus, on soil drying, is well established and concludes that the older a soil becomes the less it will respond to drying for the purpose of soil fertility. For the recovery of such soils he advocates a rest with as much moisture as possible.

Beaumont (1919) also studied the effect of drying on soil colloids and his results show an interesting parallel to the effects of drying on other soil properties. Thus drying a soil once produced as much effect on the colloidal material as repeated dryings and rewettings. Similarly Lebedjantzev found that a single drying and wetting was almost as effective as repeated dryings and wettings in increasing yield, while Birch (1958) found that a single drying and rewetting was as effective as several dryings and rewettings as regards the subsequent magnitude of decomposition. Beaumont also found that the hygroscopicity of the soil decreased successively with air-drying and oven-drying, an observation paralleled by the fact that air-drying is less effective than oven-drying with regard to the subsequent magnitudes of decomposition and nitrification on rewetting. Beaumont also noted that drying increased the amount of water-soluble humus on remoistening. He concluded that drying a soil indirectly affects the reversibility of the colloidal condition through biological and chemical action. Gustafson also considered that colloidal changes brought about by drying and heating are responsible for the increased solubility of inorganic constituents and Comber (1922) was of the same opinion. The drying effect on fertility would, therefore, appear to be closely associated with changes in the soil colloids.

With regard to some of the more recent and relevant work on this subject, Scheffer and Schroeder (1955) found an increase in lactate-soluble phosphorus in soil with increased heating from 20° to 800°C, the increase being the more marked the higher the humus and clay content of the soil.

They concluded that the phosphorus released seems to originate from organic forms adsorbed on colloidal matter. Vlamis, Biswell and Schultz (1955) found that heavily burned soils showed increased nitrogen supply over lightly burned soils and the latter over unburned soils, the effect being greater with surface soil than subsoil. A marked increase in phosphorus was shown in a sandy loam but not in the loam where fixation of phosphorus may have made phosphorus unavailable. Luebs, Stanford and Scott (1956) found that under field conditions in Iowa fluctuations in soil moisture levels in the surface one-inch layer were accompanied by marked changes in the content of exchangeable potash over an eleven week period. Below one inch exchangeable potash stayed almost constant since soil moisture content did not drop so low as in the surface. Field and laboratory studies showed that the increase in exchangeable potash was slight until the soil moisture fell below five per cent. The effect of soil drying on potash absorbed by plants was often equivalent to 60 to 120 lb potassium per acre-6 in. of soil. Soil drying also markedly affects the amount of exchangeable manganese that can be extracted. Studies at the East African Agriculture and Forestry Research Organisation (E.A.A.F.R.O.) showed that air-drying a soil (containing about 6 per cent carbon) doubled the amount of manganese extractable with neutral normal ammonium acetate while drying at 100°C increased it tenfold. Similar results have been reported in the literature. Evidently soil drying can affect a number of constituents, but it is soil nitrogen that appears to be most consistently affected and to the greatest extent. A few further examples of soil nitrogen fluctuations in relation to climate and soil drying are therefore given below.

Ap Griffith (1951) reviews some of the literature on nitrate fluctuations in the field, in relation to climate and certain cultural conditions, and then describes the nitrate fluctuations which he recorded in Uganda. With a bare soil he found nitrate production started immediately with the onset of the rainy season whilst under mulch there was only an initial small rise in the nitrate content followed by a fall. Shade was also found to reduce nitrate formation almost to the level of that under mulch. The hypothesis was advanced that a soil of given characters (texture, pH, base and humus contents, etc.) under given conditions of moisture, temperature and, possibly, insolation will show a characteristic nitrate content, and that alteration of any factor will alter this characteristic value.

Hagenzieker (1957) also followed nitrate fluctuations in the field. His results showed a topsoil flush of mineral nitrogen at the onset of the rainy season. For a grey sand this flush of decomposition was equivalent to a nitrogen application of about 2 cwt of sulphate of ammonia per acre. Yields of crops planted after the flush was over and the nitrate leached out were considerably lower than those where planting was carried out in time to catch the flush. Hagenzieker concluded that the flush must result from the mineralization of organic material derived from crop residues of the previous season and from the dead bodies of micro-organisms.

In laboratory studies on soil nitrification Cooke and Cunningham (1958) found that air-dry soils after moistening and incubation produced average increases in nitrate nitrogen (31·8 p.p.m.) approximately three times as great as the corresponding increase (10·8 p.p.m.) given by incubating fresh

soils. This difference (21 p.p.m.) is equivalent to about 210 lb of sulphate of ammonia per acre. HARPSTEAD and BRAGE (1958) found a pronounced increase in the nitrifying ability of soils on drying and storage for periods up to one year. This was thought to be due to a change, during drying, in the relative numbers of various micro-organisms which populate the soil.

Clearly soil drying has a marked effect on the fertility of the soil (particularly with regard to mineral nitrogen) which will be especially pronounced in the tropics where well defined dry seasons occur. It is important therefore to determine the underlying cause of this phenomenon for, according to RAHN (1945), ' facts can be used to greatest advantage when the reasons for the facts are completely understood '. A brief account therefore follows of current work at the E.A.A.F.R.O. on this problem which shows the conditions under which the drying effect operates, the possible mechanism involved and how this knowledge can be applied to certain agricultural practices and problems.

CURRENT INVESTIGATIONS

The first observation of interest (BIRCH, 1958) was that the drying effect was repetitive, i.e. when a dry soil was moistened a flush of decomposition and nitrogen mineralization (production of ammonia and nitrate following the decomposition of organic material) occurred. The rates of decomposition and mineralization declined after a few days, but on again drying the soil followed by remoistening the flush of decomposition re-occurred, and so on following further successive dryings and rewettings. It was also found (*a*) that the magnitude of the flush of decomposition was directly related to the humus content of the soil, (*b*) that the drying effect also occurred with a sand–humus mixture and (*c*) that the magnitude of the flush of decomposition was enhanced following the decomposition of organic material (plant material or gelatine) in the soil. Observations (*b*) and (*c*) indicated that the drying effect involved changes in the organic fraction of the soil and that the organic material involved is a product of the microbial decomposition of complex (plant material) or simple (gelatine) organic matter. This considerably limited the field of speculation as to the probable mechanism involved in the drying effect.

With regard to the drying process itself it was found that air-drying was almost as effective as more intense drying in a vacuum over phosphoric oxide, with regard both to the amount of organic material that could subsequently be extracted and the magnitudes of carbon and nitrogen mineralization on remoistening. Heating greatly enhanced these effects, whether the soil was put moist, air-dry or almost completely dry (e.g. after drying over phosphoric oxide in a vacuum) into the oven.

A time factor was then found which showed that the longer a soil was air-dried or oven-dried, without the soil necessarily becoming drier, the greater were the amounts of extractable organic material and the subsequent magnitudes of mineralization on remoistening. With air-drying the magnitudes of subsequent mineralization appear to be a direct function of the logarithm of the time the soil is in a dry state, i.e. if the amount of mineral nitrogen produced after moistening a dry soil is to be doubled, the soil has to be kept in the dry state for ten times as long.

The magnitude of the drying effect on subsequent nitrification proved to be surprisingly high. Thus, with a soil containing 7 per cent carbon the extra amounts of mineral nitrogen produced (compared with no drying) following 3, 6, 9, 12 and 17 weeks air-drying were equivalent to 1 320, 2 031, 2 350, 2 630 and 2 809 lb of sulphate of ammonia per acre. For a 6 per cent carbon soil the corresponding values were 770, 840, 1 270, 1 330 and 1 569 lb, and for a soil containing 5 per cent carbon 590, 760 and 1 040 lb (3, 6 and 12 weeks drying respectively). The results are not yet complete, but the following data for less organic soils illustrate how the drying effect falls off with decreasing organic contents. Thus, with soils containing 4, 3, 2 and 1 per cent carbon after three weeks in the air-dry state extra nitrogen was produced equivalent to 420, 185, 300 and 140 lb of sulphate of ammonia respectively.

The foregoing results demonstrate not only the magnitude of the drying effect with regard to soil nitrogen but also the operation of a fundamental principle. When a soil reaches the dry state changes take place in the organic fraction which are a function of the logarithm of the time the dry state persists, these changes being accelerated by heat. This behaviour has its parallel in the ageing of colloids and it is tentatively concluded that the drying effect involves the organic colloids of the soil. The enhanced decomposition and nitrification following the moistening of a dry soil has so far been resolved into two processes. First, drying increases the amount of organic material that goes into solution on moistening and this rapidly decomposes without producing mineral nitrogen. Secondly, and simultaneously, nitrification of organic material occurs at the humus surface, the rate of decomposition and nitrification rapidly declining. These two processes are believed to be due to the same cause, namely an enhanced exposure of organic surface to solution and microbial processes as a result of changes (increased porosity, fragmentation) in the colloids on drying and ageing, these changes being reversible on moistening with a consequent decrease in surface area and decline in the rate of decomposition. Enhanced microbial activity during the early stages of development of the microbial population may also be involved in the initial high rates of mineralization after moistening the soil.

In the field, under bare fallow, decomposition and mineralization patterns have been obtained similar to those already described. Thus at the start of the rains (equivalent to the moistening of a dry soil) decomposition and nitrification were relatively rapid but fell off quickly as the rains continued and the soil remained moist. Following the next dry season a similar pattern of behaviour occurred, and this has now been obtained from five successive wet and dry seasons.

APPLICATION TO AGRICULTURAL PROBLEMS

The results and hypothesis outlined above may now be applied to various aspects of soil fertility and other soil problems.

(*1*) Nitrogen fertilizer trials. In view of the pronounced mineralization of nitrogen that occurs when a dry soil is moistened the results of such trials will have to be considered (*a*) in relation to the length of the dry period prior to laying down the trial and (*b*) in relation to the time of laying

down the trial, i.e. whether this was in time for the crop to catch the flush of nitrate production or not.

(*2*) Early planting. This practice ensures that the crop is planted or established as coincident as possible with the start of the rains. In this way maximum advantage is taken of the flush of nitrate then produced, much of which may be subsequently lost by leaching and be unavailable to later planted crops. It would be interesting to know how much nitrogen, that could be taken advantage of by correct timing in planting, is lost by leaching each year.

(*3*) Soil burning. Heat, as already mentioned, accelerates or intensifies the changes brought about by air-drying. This practice therefore increases the amount of mineral nitrogen (ammonia or nitrate) produced when the soil is moistened. The beneficial effects of burning on soil fertility can, therefore, be related partly to this intensified production of mineral nitrogen. According to theory each of several successive burns will be effective in this way, but will cause an accelerated depletion of the organic nitrogen reserves of the soil.

(*4*) Yield–climate relationships. In these studies yield is generally related to rainfall. Suppose, however, that rainfall is adequate but that in one year a prolonged dry spell precedes the rains, while in the other the dry spell is shorter or interrupted by ' dry season ' rains. In the first instance higher yields would be expected since the magnitude of nitrification at the onset of the rains depends on the length of the period that the soil was in a dry state. In relating yield to rainfall the intensity and persistence of the dry state prior to the rains must also be considered.

In support of the foregoing supposition it may be mentioned that Laycock (1958) found a depressing effect on tea yield of ' dry season ' rain, a result which may well be due to the interruption of the length of the dry spell, as mentioned above. He also found that the increment in crop for an inch of rain in the early rains was about twice that for an inch during the main rains. This could be related to the initial high rate of nitrification at the start of the rains which rapidly falls off as the rains continue. Conversely a dry spell during the rains can have the opposite effect of ' dry season ' rains. Thus it has been reported (R. A. Wood, private communication) that in Nyasaland a dry spell during the growth of tobacco leads to excessive nitrogen uptake by the leaf when rain again falls, with adverse effects on leaf quality, the cause being due to excessive mineralization of soil nitrogen consequent upon the moistening of a dry soil.

(*5*) Irrigation. It would appear to be a good practice, when possible, to let the soil dry out prior to irrigation rather than to irrigate immediately after the rains cease. This would ensure a break in the slow rate of nitrification characteristic of prolonged moist conditions and induce a flush of nitrogen equivalent to an application of nitrogenous fertilizer. Physical conditions might also be improved, the whole leading to an effect similar to that reported earlier in relation to Laycock's work where increased yield during the early period of the rains was twice that during the later period.

(*6*) Rundown of soil fertility. This, at least with regard to soil nitrogen and carbon, appears to be a spasmodic rather than a gradual process, with the maximum rate of loss occurring at the start of each rainy season, and later

falling to a comparatively low level in spite of optimum moisture conditions. A prime factor in the rundown of soil fertility is, therefore, the intensity and persistence of the dry season insofar as this affects solution and decomposition processes at the start of the rains. The slow rate of decomposition thereafter, due possibly (as mentioned earlier) to the reduced organic surface exposed to solution and decomposition processes under prolonged moist conditions, helps to explain the persistence of organic nitrogen in soils in spite of its inherent decomposibility. In view of the fact that decomposition under moist conditions is slow, Steenkamp's recommendation mentioned earlier for the recovery of a soil through rest and constant moisture would appear to have a sound theoretical basis.

(7) Build-up of soil fertility. It has already been mentioned that following the decomposition of organic material (e.g. leaf) added to the soil the magnitudes of the succeeding flushes of decomposition following successive dryings and wettings were greater than prior to the addition of the organic material. Thus, in addition to the priming action of organic additions in hastening humus decomposition there is the fact that humus ultimately derived from the decomposition of the organic additions undergoes further decomposition and is markedly influenced by the drying and wetting cycle. This partly explains the difficulty of building up the organic and nitrogen reserves of the soil.

In conclusion it can be said that a soil at the start of the rains is very different, as regards its fertility, to the same soil later in the wet season. Substances additional to soil nitrogen may be involved, for example phosphorus, potassium, manganese and other elements but the greatest and most consistent effect of soil drying appears to be on soil nitrogen. Changes in the physical state of the soil, from a more open structure at the start of the rains to a less porous and more poorly aerated state later on, as the soil colloids swell and come to equilibrium, may also be involved. Another possibility is that the organic material going into solution when a dry soil is wetted contains a compound which stimulates plant growth, but which is readily leached away because of its solubility. These possibilities can readily be tested. Meanwhile the effect of soil drying on increasing the amount of mineral nitrogen appears to be established and affords a partial explanation at least for the effect of drying on soil fertility.

SUMMARY

A brief review of the literature is given which illustrates the beneficial effect of soil drying on soil fertility. While drying increases the availability of several elements, soil nitrogen appears to be most largely and consistently affected. Improved physical conditions following drying may also be involved, but this is less well established.

Recent work on the effect of drying on humus decomposition and nitrification is then discussed. The effect of soil drying on the amount of mineral nitrogen produced on moistening is largely a function of the humus content of the soil and the logarithm of the time the soil is in an air-dry state prior to moistening. The amounts of mineral nitrogen produced in this way are sufficiently large, even with soils poor in humus, to exert a considerable influence on soil fertility. A possible explanation for the drying effect is

then given and this hypothesis, together with the recorded observations, is applied to various aspects of agriculture such as nitrogen fertilizer trials, irrigation, and the rundown of soil fertility.

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West Indian 'Dioscorea alata' *Cultivars*

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Dioscorea alata is a polymorphic species grouped in the section Enantiophyllum and described by Prain and Burkill (1914) and Burkill (1917). Roxburgh (1874) gave a fairly full description under *D. alata*. He also described *D. atropurpurea*, *D. globosa*, *D. purpurea* and *D. rubella*, all of which Burkill (1914) regarded as varieties. Vavilov (1951) listed it with the plants of the Hindustan centre of origin and Burkill (1950) gives an excellent account of its spread to Polynesia and indirectly suggests that it was present in the West Indies by 1550. Probably the first botanical record of *D. alata* in the West Indies was made by Sloane (1707).

As the tubers possess excellent storage qualities, they were used extensively for provisioning the ships of early traders which accounted for many early introductions. In recent years (Kinman, 1921) cultivars have been imported into Puerto Rico for experimental purposes from Ceylon and New Guinea.

As these cultivars thrive in the West Indian climate, and due, no doubt, to their high yielding capacity, which help to make them a relatively cheap source of carbohydrate, they have gradually assumed a very important part in the diet. They generally grow well in the hilly areas which are unsuitable for rice production and they seem to be higher yielding than an indigenous species *D. trifida*, and probably more adaptable to commercial agriculture.

It is in the Eastern Caribbean that ' alata ' yams are extensively grown; in Jamaica species of African origin are still very important. In the region there has been no coordinated description and evaluation of the cultivars and synonymy is widespread. Burkill's papers of 1917 and 1924 dealt fairly fully with certain aspects of these problems in Malaya, and Williams (1925) briefly commented on the problems in the West Indies. A real need exists for a greater understanding of the crop in order to achieve improvement.

The initial problem, that of classification, is rendered difficult by the variation in tuber shape and size caused by varying soil type and condition. Highly compacted soils cause normally ' deep going ' tubers to spread laterally, while open friable soils containing large quantities of humus tend to produce extremely large and commercially useless tubers.

Besides the difficulties of classifying on tuber characters, several cultivars exist, which have identical foliage; these, however, produce tubers which are readily distinguishable even when grown in adjacent plots. Variation in the location and intensity of pigmentation of the aerial parts is important diagnostically and it has been found necessary to base a preliminary field

key on these characters. Gross morphological features are probably more acceptable to some workers due to the fading of pigmentation when the plants are dried. However, detailed descriptions of other variations are included.

Observations recorded in this paper have been made on planting material obtained mainly from Trinidad, Tobago, Barbados, St Vincent, Montserrat and Jamaica. This material has been planted in the experimental gardens at the I.C.T.A. Because no reports of seedlings, or actual seedlings, have been found in the West Indies, it is considered that the variability has been fairly well sampled. The climatic differences of the islands mentioned are considerable, and as yam cultivars appear so plastic in their reaction to the environment, ' transplant ' studies of this nature seem essential for confirmation of correct grouping in many instances.

METHODS OF COLLECTION AND STUDY

The cultivars were collected during the course of a survey of the variation in starchy root crops in the Federated West Indian islands. The survey was started in December 1956 and is still in progress. Tuber samples were either obtained personally from peasant farmers or forwarded to the I.C.T.A. by the Departments of Agriculture in the islands visited.

The collections, except from Jamaica, were made in 1956–57 and planted in the food crops experimental area at the I.C.T.A. in June 1957, before the commencement of the wet season. The Jamaican collection was planted in June 1958 when the original collection was replanted. The cultivars were grown in the same way as a commercial ' White Lisbon ' crop except that the spacing was 4 feet by 3 feet. For commerce, four ounce pieces of tuber are planted on ridges prepared by filling trenches with dried sugar-cane foliage and covering with a few inches of soil. These ridges are usually made 4 feet apart and run along cambered beds, the yams being planted 1 foot to 2 feet apart on the ridges. Between these ridges bamboo poles are erected to serve as supports for the vines. Due to the drainage differences which exist on these cambered beds all the observation plants, two of each accession, were planted on the two central ridges where conditions were most uniform. Any additional plants were grown elsewhere on the beds and used for multiplication purposes and general observations on yield. All the cultivars were planted on the same date in the 1957 season but in 1958 they were planted in order of sprouting.

Foliage descriptions were made in 1957 and tuber and foliage descriptions in 1958. These descriptions covered the range of sizes, weights, shapes and pigmentation of tubers. Details of the total length and breadth of leaves, the length and the angle subtended by the main veins of the basal lobes, pigmentation of petioles and other morphological features were also included. From these observations a key was constructed and synonyms eliminated. Specimens of each of the cultivars described will be lodged in the I.C.T.A. herbarium.

A KEY TO THE CULTIVARS

This key has been prepared using foliage characters in the first place as the tubers are generally only available for four months of the year. With

certain cultivars both foliage and tuber characters must be known in order to make a positive identification.

1.	Leaf axils green only	2
	Leaf axils rarely green only, usually greyish green, with or without a suggestion of magenta to dark or bright magenta	4
2.	Plant generally lacking anthocyanin pigmentation but with red wings, tubers cylindrical to ovoid and shallow rooted	' Barbados '
	Plants generally lacking anthocyanin pigmentation, wings pale green	3
3.	Basal lobes of leaves usually pointed, the lower stem often lightly mottled. Tubers usually divided to form two fingers, shallow rooted	' Hunte '
	Basal lobes of leaves usually rounded, lower stem not mottled, auricles of basal lobes bent upwards. Tubers deep rooting with a long neck and fingered	' Bottleneck Lisbon '
4.	Leaf axils rarely green only, usually greyish green to dark magenta in adaxial region of petiole only	5
	Leaf axils bright magenta all around the petiole, outer cortex of tubers usually magenta	10
5.	Leaves dark green, sometimes almost hastate, sinus with a wide angle; lower stem prickly and heavily mottled, dark purple. Tubers fingered	6
	Leaves medium green, never hastate, sinus with a narrow angle, lower stems not prickly and rarely mottled	7
6.	Tubers shallow rooted with a short neck	' Ginger '
	Tubers deep rooted with a long neck	' Long Finger '
7.	Mature leaves often small, stem wings often scarlet edged, basal lobes of leaves rarely overlap. Leaves often green mottled, plant dwarf. Tubers globular to barrel-shaped	' Coconut Lisbon '
	Mature leaves large, stem wings not scarlet, basal lobes of leaves sometimes overlap, leaves not mottled, plant usually vigorous	8
8.	Plant often weak growing, lamina not usually ' ridged ' between the main veins, older leaves usually distinctly hyaline edged, tubers single, long, cylindrical and curved	' Horn '
	Plant strong growing, lamina surface raised between main veins, older leaves not distinctly hyaline edged	9
9.	Tubers shallow rooted rarely more than 12 inches long and often fingered, with a short ' neck ' to the tuber	' White Lisbon '
	Tubers deeply rooted, with a long ' neck ' and fingered	' Bottleneck Lisbon '
10.	Leaf axils only bright magenta, petioles green only at junction of lamina and petiole, except for wings; no red stain at sinus. Leaves medium to dark green	11
	Leaf axils bright magenta, petioles bright to pale magenta at junction of lamina and petiole. Red stain usually present in leaf sinus	12
11.	Lower regions of main stem slightly mottled and/or prickly. Tubers deeply rooted, often 18 inches or more long or ridged	' Wild '
	Lower region of main stem not mottled or prickly, leaves with well rounded basal lobes. Multiple tubers often 12 inches long but not coarse and ridged as in (11)	' Sweet '
12.	Leaves small, vines often weak growing, lower stems never prickly. Tuber globular to barrel-shaped	' Oriental '
	Leaves large, vines strong growing, stem thick, lower regions of stems occasionally prickly	13
13.	Basal lobes of mature leaves never overlapping, leaves very dark green, sometimes almost hastate. Lower stems very prickly and purple mottled, tuber long necked and fingered	38/57 ' Wild Red '
	Basal lobes of mature leaves often overlapping, leaves medium to dark green, stems occasionally slightly prickly and slightly mottled	14
14.	Leaves often red veined, tubers deep rooted, ridged and shortly fingered	' Butterfly '
	Leaves not red veined, tubers single or many fingered	15
15.	Tuber flesh red/magenta	' St Vincent Red '
	Tuber flesh white or pinkish	16
16.	Tuber single, long and curved	' Red Cane '
	Tuber many fingered	' Moonshine '

VERNACULAR SYNONYMS AND PROPOSED CULTIVAR NAMES

BURKILL (1924) mentions several names which are used in Asia; many of these are also used in the West Indies, for instance, ' Coconut ', ' Horn ', ' White ', ' Red ' and ' Devil '. These names are descriptive of tuber shape and colour or deprecatory.

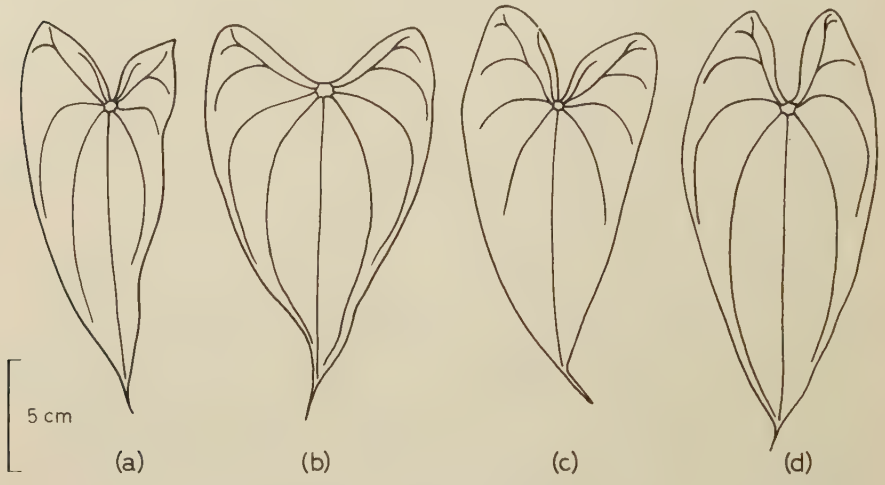

Figure 1. Leaf forms of non-pigmented D. alata *cultivars.* (a) ' *Hunte* ', (b) ' *Long Finger* ', (c) ' *Coconut Lisbon* ', (d) ' *White Lisbon* '

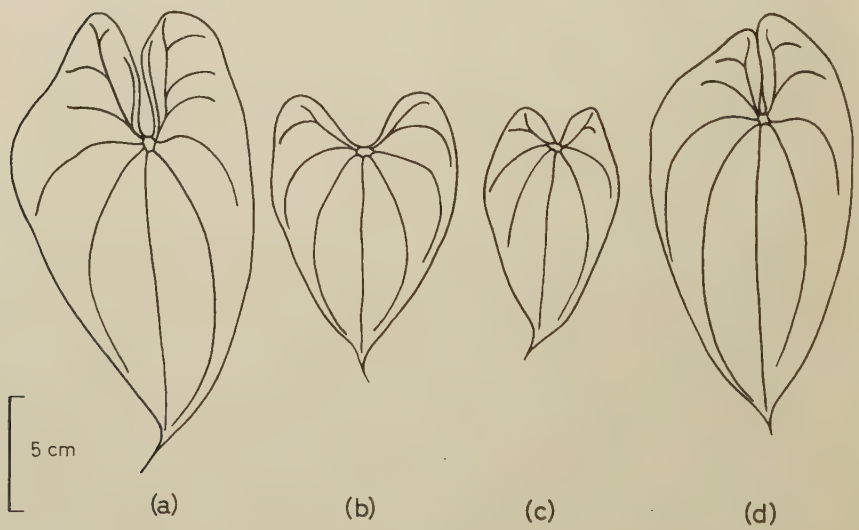

Figure 2. Leaf forms of pigmented D. alata *cultivars.* (a) ' *Wild* ', (b) ' *Sweet* ', (c) ' *Oriental* ' (d) ' *Moonshine* '

In *Table 1*, the cultivars are first numbered in the order that they appear in the key and secondly by the accession number which identifies individual

clones. A cultivar name has been proposed for those accessions which would seem to be best placed together because of their great similarities. A list of probable vernacular synonyms is given in *Table 2*; this is based on descriptions obtained from various Agricultural Department officials and farmers and from identifications of these yams from colour slides and actual specimens by visitors to Trinidad.

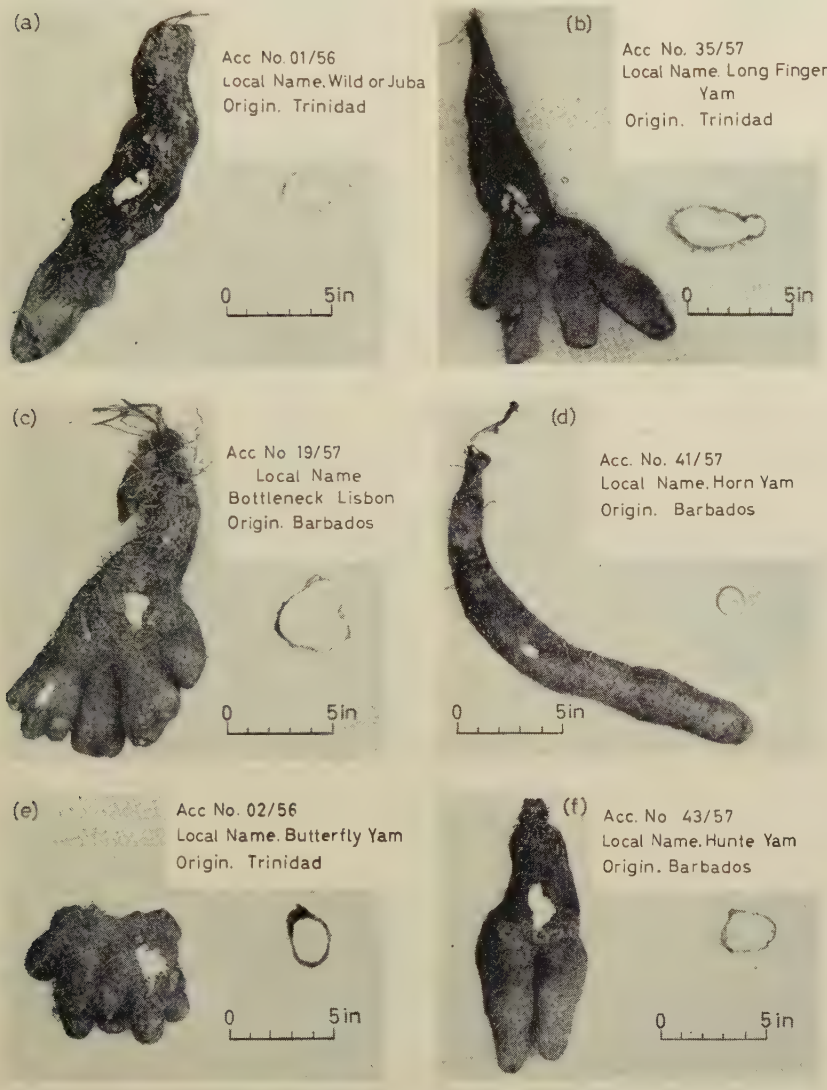

Figure 3. (a) ' *Wild* ', (b) ' *Long Finger* ', (c) ' *Bottleneck Lisbon* ', (d) ' *Horn*', (e)' *Ginger* ', (f) ' *Hunte* '

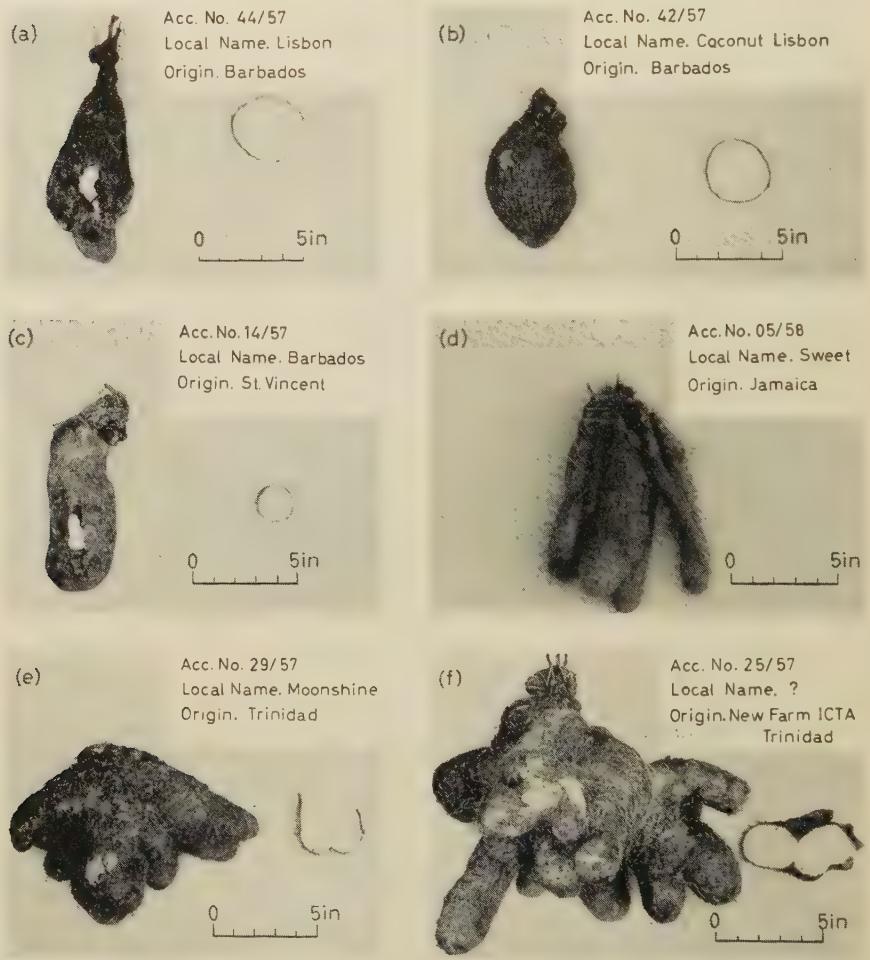

Figure 4. (a) '*White Lisbon*', (b) '*Coconut Lisbon*', (c) '*Barbados*', (d) '*Sweet*', (e) '*Moonshine*', (f) 25/27 *a* '*Moonshine*' *from the I.C.T.A. commercial* '*Lisbon*' *crop*

GENERAL DESCRIPTIONS OF THE CULTIVARS

(1) '*Barbados*' [*Figure 4* (c)]

Stems are purple mottled at the base and never prickly. Wings are reddish, except on the very young stems where they are translucent. The auricles of the basal lobes of most leaves are bent upwards at right angles to the main lamina surface, the angle between the veins in the basal lobes is generally 15° to 45°.

Petioles are green except for the wings which are red edged on the immature petioles.

Tubers are cylindrical to globular and dark skinned with very few roots. Immediately below the periderm the flesh is often light pink while the remainder of the cortex is white. Tubers will store successfully for at least five months. This cultivar could be mechanically harvested.

Table 1. Established vernacular synonyms

Cultivar number	*Accession number*	*Vernacular name*	*Island*	*Name used*
1	14/57	' *Barbados* '	*St Vincent*	' *Barbados* '
2	43/57	' *Hunte* '	*Barbados*	' *Hunte* '
3	15/57	' *Hadley Barbados* '	*St Vincent*	' *Bottleneck Lisbon* '
	19/57	' *Bottleneck Lisbon* '	*Barbados*	
4	02/56	' *Butterfly* '	*Trinidad*	' *Ginger* '
	30/57	' *Ginger* '	*Trinidad*	
	36/57	' *Short Finger* '	*Trinidad*	
5	35/57	' *Long Finger* '	*Trinidad*	' *Long Finger* '
6	42/57	' *Coconut Lisbon* '	*Barbados*	' *Coconut Lisbon* '
7	05/56	' *Horn* '	*Grenada*	' *Horn* '
	08/56	' *Horn* '	*St Vincent*	
	07/56	' *White Cane* '	*Grenada*	
	41/57	' *Horn* '	*Barbados*	
8	03/56	' *Lisbon* '	*Trinidad*	' *White Lisbon* '
	13/57	' *White Lisbon* '	*St Vincent*	
	31/57	' *White Lisbon* '	*Trinidad*	
	44/57	' *Lisbon* '	*Barbados*	
9	01/56	' *Wild* ' ' *Juba* '	*Trinidad*	' *Wild* '
	08/56	' *Bush* '	*Grenada*	
	32/57	' *Devil* '	*Trinidad*	
	37/57	' *Bottleneck* '	*Trinidad*	
	06/58	' *Renta* '	*Jamaica*	
	12/58	' *Wild* '	*Trinidad*	
	03/57	' *Ben* ' ' *White* '	*Tobago*	
	11/57	' *Sambo* '	*St Vincent*	
10	05/58	' *Sweet* '	*Jamaica*	' *Sweet* '
11	40/57	' *Danish* '	*Barbados*	' *Oriental* '
	39/57	' *Oriental* '	*Barbados*	
	16/57	' *Mushapla(t)* '	*St Vincent*	
12	38/57	?	*Trinidad*	' *Wild Red* '
13	26/57	' *Butterfly* '	*Trinidad*	' *Butterfly* '
	27/57	' *Cumoto* '	*Trinidad*	
	28/57	' *Red* '	*Trinidad*	
14	04/58	' *St Vincent Red* '	*Jamaica*	' *St Vincent Red* '
15	06/56	' *Red Cane* '	*Grenada*	' *Red Cane* '
16	09/56	' *Moonshine* '	*Grenada*	' *Moonshine* '
	29/57	' *Moonshine* '	*Trinidad*	
	02/57	' *Sweet* ' ' *Tangu* '	*Tobago*	
	13/56	?	*Montserrat*	
	17/57	' *Red Bascombe* '	*St Vincent*	
	06/57	' *Red Renter* '	*Tobago*	
	09/58	' *St Vincent* '	*Jamaica*	
	28/57	' *Red* '	*Trinidad*	
	11/58	' *Wild Red* '	*Trinidad*	

(2) ' *Hunte* ' [*Figure 1* (a), *Figure 3* (f)]

Stems are purple mottled at the base and never prickly, the wings are purple edged. The leaves are pale green and concave with a hyaline margin, the basal lobes are often pointed.

Angle of basal lobe veins varies between 40° and 70°.

Anthocyanin pigmentation is absent from the petioles but it is present on the ' stipules ' which are faintly reddish.

The tubers are usually free from roots and divided at half their length to form two large ' fingers ' which are sometimes spread at right angles. The outer cortex is cream with an occasional greenish tinge, the ' flesh ' is white.

Tubers will store successfully for five months. Aerial tubers are sometimes produced.

The cultivar appears to be high yielding but it tends to be too deeply ' rooted ' for mechanical digging.

Table 2. Probable vernacular synonyms

Cultivar name	*Probable vernacular synonyms*	*Island*
' *Barbados* '	' *Ashmore* '	*Grenada*
' *Bottleneck* '	' *Lisbon 638* '	*Dominica*
	' *Bottleneck* '	*Dominica*
	' *Barbados Renta* '	*Jamaica*
' *Coconut Lisbon* '	' *Hard* '	*Jamaica*
	' *Barrel* '	*St Vincent*
' *Horn* '	' *Snake* '	*Jamaica*
' *White Lisbon* '	' *Trinidad Renta* '	*Jamaica*
	' *White* '	*Jamaica*
	' *Table* '	*St Vincent*
	' *White Bascombe* '	*St Vincent*
' *Wild* '	' *Cut and Throw away* '	*Dominica*
	' *Baggu* '	*Grenada*
	' *Bragging Tom* '	*Jamaica*
	' *Banja* '	*St Lucia*
	' *Bobus* '	*St Vincent*
	' *Cut and Throw away* '	*St Vincent*
	' *Cut and Throw away* '	*Trinidad*
' *Oriental* '	' *Oriental* '	*Dominica*
' *St Vincent Red* '	' *St Vincent* '	*Jamaica*
	' *Blue Vine* '	*Jamaica*
	' *Red* '	*Jamaica*
	' *Dark Night* '	*Jamaica*
' *Butterfly* '	' *Babaouli* '	*Dominica*
	' *Duck* '	*Dominica*
' *Moonshine* '	' *Moon* '	*Dominica*
	' *Moonshine* '	*Dominica*
	' *Red Lisbon* '	*Dominica*
	' *Water* '	*Grenada*
	' *St Kitts* '	*Grenada*
	' *Red* '	*Jamaica*
	' *Red Renta* '	*St Vincent*
	' *Barbados Mix Colour* '	*St Vincent*
	' *Moonshine* '	*St Vincent*
	' *Water* '	*St Vincent*

(3) ' *Bottleneck Lisbon* ' [*Figure 3* (c)]

Stem bases are slightly mottled and without prickles, wings are faintly purple edged. The basal lobes of the leaves are slightly pointed to rounded and overlap. The lamina is flat and has a faint reddish margin.

Basal lobe vein angles show wide variations but they are typically about 40° to 50°. Leaf axils are greyish in the adaxial region.

Tubers are often 30 cm long with a long ' neck ' and ' fingered '; they are moderately covered with roots. Outer cortex is cream and flesh white.

The ' White Lisbon ' appears to be a selected shallow ' rooting ' form of this yam.

(4) ' *Ginger* ' [*Figure 3* (e)]

This cultivar is characterized by a prickly and magenta mottled lower main stem which is 4 to 7 winged except at the base which is wingless. The

leaves are dark green and tough with a broad sinus and often possess a magenta margin. Very young leaves have a blackish acuminate apex. Typical leaves have a basal lobe vein angle varying between 60° and 100°. The leaves are often broader than long.

The tubers are highly digitate with many roots and therefore commercially useless. The outer cortex is pale yellow, flesh is white. Small irregularly shaped aerial ' tubers ' are produced.

(5) ' *Long Finger* ' [*Figure 1* (b), *Figure 3* (b)]

The aerial parts are identical with ' Ginger ' except for being more vigorous. Tubers are often 45 cm or more long, consisting of a 30 cm ' neck ', which occasionally grows out from the soil, and terminated by long thin ' fingers '. They possess many roots. The outer cortex is light pink, flesh is white.

Yield averaged only 1·4 kg per plant, it is useless because of its deep ' rooting ' habit.

Because of the great differences between cultivars 4, 12 and 5 and the rest they might be incorrectly grouped with *D. alata*. For this reason *D. alata* has been placed in inverted commas in the title.

(6) ' *Coconut Lisbon* ' [*Figure 1* (c), *Figure 4* (b)]

This cultivar is recognizable by the scarlet to magenta corrugated wings on the stems. The stem base is magenta mottled but never prickly. Leaves are often smaller than most cultivars and are typically 11 to 12 cm long and 8 to 9 cm broad. The basal lobe vein angle is about 60°, these lobes rarely overlap and are rounded. Petioles are greyish to faint magenta in the adaxial region similar to ' White Lisbon '.

Tubers are usually ovoid and the skin or periderm is coarse and thick. The outer cortex is cream becoming slightly orange on storing, flesh is white. The tubers appear identical to the ' Danish ' described by Williams (1925).

The average yield per plant was very low and many were dwarfed, the leaves being yellow mottled and wrinkled. A virus infection is suspected. Since this cultivar, like ' Barbados ', stores extremely well and produces a good shaped shallow rooted tuber it is potentially very valuable.

(7) ' *Horn* ' [*Figure 3* (d)]

The stem bases are sometimes slightly purple mottled but never armed. The basal lobes of the leaves do not overlap and the lamina is noticeably flat. Old leaves often have a silvery sheen and most leaves possess a distinctly hyaline margin. Leaves are typically long and have a basal lobe angle of 50° to 60°. The leaf axils are often darkish grey in the adaxial region only.

The tubers range from about 30 to 45 cm long and 3 to 6 cm in diameter; they are usually cylindrical and curved but occasionally straight. The outer cortex is usually white to pale yellow but occasionally pink, the ' flesh ' is white. Under cultivation at the I.C.T.A. Horn has yielded badly and 250 g per plant was common. It is early maturing. A rich deep friable soil appears to be required for the tuber to develop fully. Commercially it is

useless, although it will store fairly well and is liked by many people because of its good cooking qualities.

(8) ' *White Lisbon* ' [*Figure 1* (d), *Figure 4* (a)]

The main stem base is very slightly mottled but never armed. Leaves are ridged between the primary veins, and the basal lobes rarely overlap but one is usually 2 to 3 mm longer than the other. This difference in basal lobe length is common in most of the cultivars described but it is not usually so pronounced as in ' White Lisbon '. Leaves vary from 10 to 16 cm in length and from 6 to 11 cm in breadth. The angle of the basal lobe veins varies between 35° and 55°. Petioles are greyish to occasionally dark magenta, in the adaxial region only.

There is a wide range of variability in tuber shape but they are nearly always under 30 cm long. The ' neck ' of the tuber varies in length from 2 to 3 cm to 7 to 8 cm and the main portion of the tuber can be clavate to digitate. A typical specimen has a 5 cm neck dividing to form two to three finger-like portions with a total length of 20 cm. The outer cortex is creamy white and the flesh is white.

During the 1957–58 season the yield average per plant in the multiplication plots was 800 g (from 137 plants), the highest yield being 3·4 kg and the lowest 150 g. One of the reasons for this wide range is due to the planting pieces being derived from different portions of the tuber, although they were all of the same weight. It has already been shown (Mackie, 1925) that planting pieces derived from the upper portion of the perennial stem or ' head ' of the yam yield the best. The reason seems to be partly due to the adventitious buds sprouting more quickly in this region than in any other (Burkill, 1915), thus giving the plant an early start. This allows the plants a full season of growth before being prematurely dried due to lack of moisture in the dry season. Burkill (1950) mentions the transfer of leadership by drying of the most apical bud as one of the secrets of the keeping quality of the yam.

This cultivar stores extremely well for five to six months if not cut in harvesting; it is also very palatable and high yielding. Because of the widespread cultivation of ' White Lisbon ', an attempt is being made to determine whether any significant genetic differences exist in yielding capacity of the various clones of this cultivar.

(9) ' *Wild* ' [*Figure 2* (a), *Figure 3* (a)]

The base of the main stem is occasionally slightly prickly, purple mottled and rounded. The old leaves are fairly tough and their basal lobes sometimes overlap although the angle subtended by the veins of these lobes increases with age as is the case with other cultivars. The leaves are usually red to hyaline edged and the main veins of the basal lobes, on the under-surface of the leaf, are usually pink and winged.

The petioles are dark magenta at the leaf axils only; this pigmentation rings the petiole as distinct from any of the previously described cultivars.

The tubers grow straight down for 50 cm or more and possess many roots. In transverse section they are irregularly ridged. Outer cortex colour varies from pink to yellow and white. Usually near the large corky and tough

' head ' the periderm is pink and the flesh orange. It is from this large ' head ' or perennial stem that the name ' Cut and throw away ' is derived. Yields are often 4·5 kg per plant when using commercial cultivation methods but they can be grown to a much greater weight, as can ' White Lisbon ', by growing them in specially prepared pits filled with humus and by providing a large pole to support the vines.

Many selections of this cultivar are grown varying in the degree of ridging of the tubers, but all possess ' deep-going ' tubers rendering them useless for mechanical harvesting. They are all late maturing and bear aerial bulbils.

(10) ' *Sweet* ' [*Figure 2* (b), *Figure 4* (d)]

This cultivar has only been seen in Jamaica. The pigmentation of the vines is similar to the ' Wild '. The angle subtended by the main veins of the distinctly rounded basal lobes is usually over 65° and occasionally exceeds 90°. The main stems are not mottled, and prickles are absent.

The petioles are distinctly magenta at the leaf axils but rarely pigmented at the lamina–petiole junction.

The tubers are distinctive in being multiple. They can be rounded or slightly ridged, the outer cortex and flesh is white. In Jamaica the tubers of this cultivar are said to be a good substitute for those of *D. trifida*, due to their excellent eating qualities.

(11) ' *Oriental* ' [*Figure 2* (c)]

The stems are never prickly or mottled. The leaves are much smaller than most other cultivars and are a darker green than ' White Lisbon '. The angle of basal lobe veins is rarely under 70° and often exceeds 100°.

Petioles are bright magenta at the stem junction and pale magenta at the lamina junction, a red stain is usually present in the leaf sinus.

Tubers possess very few roots and are typically ovoid with a thick skin, the outer cortex is red to magenta, flesh is white. They vary a great deal in size according to environment; in dry conditions they are usually about 20 cm long and 10 cm at the maximum diameter but in fertile damp soil they can be 30 cm long. The period to maturity is a little longer than for ' White Lisbon ' but as with all other pigmented cultivars examined they should be planted earlier because of early sprouting in storage.

This cultivar is a good commercial type and often imported into Trinidad from Barbados.

(12) ' *Wild Red* '

The basal stems are darkly purple mottled and prickly. Leaves are large, dark green and fairly tough, the basal lobes never overlap. Petioles are dark red at lamina and stem junctions, a red stain is present in the leaf sinus. The aerial parts are rather similar to ' Long Finger ' except for pigmentation.

The tubers are very deep ' rooted ' like ' Wild ' but they are not usually ridged and at the distal end two or three fingers are often present. The outer cortex is purple and the flesh is usually pale orange particularly near the ' head ' where both colours are intensified.

(13) ' *Butterfly* '

The wings of the purple mottled lower stems are often modified to form ' prickles '. Leaves are dark green with rounded basal lobes which never overlap, margins are red to hyaline and the veins are often red. Petioles are magenta at lamina and stem junctions, a red stain is present in the sinus which has a large angle. Aerial bulbils are produced.

Tubers are often 30 cm long and digitate, they mainly resemble ' Moonshine ', except that pigmentation is a much darker purple in the outer cortex. They are well covered with roots.

(14) ' *St Vincent Red* '

The foliage is practically identical with that of ' Moonshine ', but the tubers have red to dark magenta flesh and appear to be less deeply ' rooting ' than those of ' Moonshine ', but are digitate. Tubers sprout early in storage.

(15) ' *Red Cane* '

The stems are unarmed and slightly purple mottled. Petioles are magenta at leaf and stem junctions. Basal lobes of the leaves rarely overlap. Tubers are long and cylindrical. (Very little information is available on this cultivar as it died off early in the 1957–58 season during dry weather.)

(16) ' *Moonshine* ' [*Figure 2* (d), *Figure 4* (e), (f)]

The lower stems of this cultivar are sometimes purple mottled but never armed. Stem wings are magenta. All but the oldest leaves possess a red stain in the sinus and the basal lobes usually overlap. Leaf margins are faintly red to hyaline.

The angle of the basal lobe veins is usually between zero and 20°. Petioles are bright magenta at the stem junctions and pink to light magenta at lamina junctions.

Tubers are highly digitate, and the outer cortex is red, the colour of which shows through the periderm when the tuber is freshly washed, the pigmentation being more strongly concentrated around the adventitious buds. The tubers soon sprout in storage and are easily damaged during harvesting due to their excessive digitation. Aerial bulbils are often formed.

This cultivar is widely grown in small gardens in the eastern Caribbean probably because of its high yield.

A good deal of variation exists in pigmentation in the various clones but the cultivar is readily recognizable. It would be useless for commercial mechanized cultivation.

LEAF VARIATION

With the aim of distinguishing the cultivars on leaf characters alone, other than on pigmentation which fades in dried material, various leaf measurements were made. Measurements were taken on leaves at three months from planting and at five to six months from planting. Leaf breadth, measured at the sinus; leaf length, from sinus to apex; petiole length and diameter; and the angle subtended by the main veins of the basal lobes, were studied.

Table 3. Leaf measurements

Cultivar No.	Cultivar Name	Leaves of plants 3 months old: No. of leaves in sample	Mean leaf ratio	Std Devn of leaf ratios	Mean leaf length (to nearest cm)	Mean angle of basal lobe veins (nearest degree)	Std Devn of angle (nearest degree)	Leaves of plants 5 to 6 months old: No. of leaves in sample	Mean leaf ratio	Std Devn of leaf ratios	Mean leaf length (to nearest cm)	Mean angle of basal lobe veins (nearest degree)	Std Devn of angle (nearest degree)
1	*'Barbados'*	10	1·71	±0·110	15	21	± 4	40	1·98	±0·154	13	43	± 3
2	*'Hunté'*	20	1·51	±0·122	14	62	±19	30	1·72	±0·118	12	69	± 4
3	*'Bottleneck Lisbon'*	15	1·43	±0·100	12	39	±17	20	1·67	±0·141	12	48	± 3
4	*'Ginger'*	20	0·94	±0·071	11	60	±12	30	1·35	±0·100	10	86	±18
5	*'Long Finger'*	10	1·10	±0·095	12	70	±11	10	1·32	±0·045	10	102	± 2
6	*'Coconut Lisbon'*	15	1·40	±0·084	12	63	± 9	30	1·43	±0·110	11	65	± 3
7	*'Horn'*	20	1·47	±0·124	16	53	±13	10	1·56	±0·148	13	50	± 6
8	*'White Lisbon'*	30	1·43	±0·145	14	40	± 8	50	1·63	±0·145	12	52	±14
9	*'Wild'*	20	1·28	±0·089	13	36	± 8	70	1·46	±0·187	12	48	±10
10	*'Sweet'*	10	1·42	±0·158	14	72	±14	10	1·45	±0·095	10	85	±19
11	*'Oriental'*	20	1·37	±0·100	11	82	±11	40	1·68	±0·145	8	94	±25
12	*'Wild Red'*	20	1·37	±0·176	13	80	±14	10	1·72	±0·105	10	80	±14
13	*'Butterfly'*	30	1·34	±0·167	14	72	±14	40	1·36	±0·114	12	93	±17
14	*'St Vincent Red'*	10	1·57	±0·190	12	10	± 3	10	1·93	±0·145	9	10	± 3
15	*'Red Cane'*	*Not measured due to very retarded growth*						10	1·68	±0·184	9	54	± 6
16	*'Moonshine'*	20	1·40	±0·134	13	22	± 9	50	1·68	±0·130	10	25*	±18

* *Many of the entries were zero.*

The angle proved difficult to measure accurately due to the rapid wilting and curling of the leaves after picking. In certain cultivars which have rather thin leaves and where the angle is partly made up by a natural concavity, inaccuracies were unavoidable.

From the beginning of this study it was obvious that leaf size and shape varied on individual cultivars but the means of typical leaves were generally distinctive for the various cultivars. In order to obtain an accurate picture of leaf form, leaves were chosen from the main stems at between two and five feet from ground level. Any atypical leaves were discarded. Due to the complex interweaving of the vines it was found impossible to define leaf positions more accurately.

Measurements were made on a minimum of ten leaves per cultivar and altogether more than 700 leaves were recorded. *Table 3* summarizes the more important measurements. If the leaf ratios and angles are plotted graphically it is readily evident that there is a general increase in one or both with increase in age of the plant. The main exceptions are ' Coconut Lisbon ' and ' Horn '. These cultivars both grew extremely badly, the former because of a probable virus infection and the latter due probably to unsuitable environmental conditions. ' Red Cane ' was omitted at the three-months measurements due to the very poor growth. The data quoted, although for 5 to 6 months, probably represent a normal plant of this cultivar at 3 months.

The leaf characteristics may be summarized generally as follows:

Cultivar 1. High leaf ratio 1·7 to 2·0.

Cultivar 2. [*Figure 1* (a)]. Leaves usually over 12 cm long with an angle of over 50° and pointed basal lobes.

Cultivars 3 and 8. [*Figure 1* (d)]. Angles mainly 40° to 55° and lamina ridged between the main veins in Cultivar 8.

Cultivars 4, 5 and 12. [*Figure 1* (b)]. Low leaf ratio, angle always over 60°. Leaves tough.

Cultivar 6. [*Figure 1* (c)]. Angle about 60° and leaves fairly small, usually from 11 to 12 cm long.

Cultivar 7. Leaves long, often 13 to 16 cm; angle about 50°.

Cultivar 9. [*Figure 2* (a)]. Typically large leaves, broader than most cultivars.

Cultivars 10 and 11. [*Figure 2* (b), (c)]. Small leaves with angles 60° to 100°. Leaves of cultivar 10 often a little broader and basal lobes distinctly rounded.

Cultivar 13. Similar to 9, but basal lobes usually with a larger angle.

Cultivars 14 and 16. [*Figure 2* (d)]. Leaves about 9 to 13 cm long and angles usually below 25° and often zero.

An attempt was made to separate all the cultivars graphically on a multiple scatter diagram. The best separation was obtained by plotting leaf ratio times petiole length against the angle, but it was not satisfactory.

Since previous work had described the petioles as being ' one third or one half as long as the blade ' or ' nearly as long as the leaves ', it seemed interesting to determine whether any relation existed between petiole and lamina length. For this purpose correlation and regression coefficients were calculated for ten pigmented and ten non-pigmented cultivars [*Tables 4* (a) and *4* (b)].

Generally the regression coefficients for the individual cultivars were extremely low and varied considerably. The correlation coefficient (r_{yx} in *Table 4*) for cultivars 9 to 16 was very high, but low for cultivars 1 to 8. An interesting result was the great similarity between the average correlation coefficients (r in *Table 4*) of both the groups; they were low and almost

equal. It is also notable that the petioles of the ' Wild ' and ' Butterfly ' cultivars, both poor quality yams often occurring near forest areas, are long. In contrast to this the highly selected yams such as ' Oriental ' tend to have much shorter petioles and smaller leaves. Cultivars 4, 5 and 12 are exceptions but they do not appear to be *D. alata* L. because of their prickly lower stems (this character is not persistent, however).

Table 4 (a). *Regression of petiole length on lamina length: cultivars with non-pigmented tubers*

Cultivar No.	*Name*	*Accn No.*	*Mean* petiole length* $\bar{y}$ *cm*	*Mean* lamina length* $\bar{x}$ *cm*	*Regression of y on x b*	*S.E. of b*	*Corr. coeff. of y and x r*
1	' *Barbados* '	14/57	6·8	13·4	−0·29	±0·29	−0·33
2	' *Hunte* '	43/57	7·9	12·0	+0·42	±0·66	+0·22
2	' *Hunte* '	43/57	7·1	12·1	+0·68	±0·29	+0·63
3	' *Bottleneck Lisbon* '	15/57	7·2	11·8	+0·61	±0·25	+0·66
4	' *Ginger* '	36/57	5·8	9·5	+0·43	±1·22	+0·12
4	' *Ginger* '	02/56	8·6	10·8	+1·11	±0·56	+0·57
5	' *Coconut Lisbon* '	42/57	6·5	11·1	+0·20	±0·38	+0·18
7	' *Horn* '	07/56	8·4	13·3	−0·02	±0·30	−0·02
8	' *White Lisbon* '	44/57	7·0	12·1	+1·01	±0·30	+0·77
8	' *White Lisbon* '	31/57	6·6	12·8	+0·06	±0·11	+0·18
Mean values			7·2	11·9	+0·42		+0·30

* Means based on ten measurements.
Association between cultivar means:
r_{yx} = +0·312
b_{yx} = 0·23 ±0·25

Table 4 (b). *Regression of petiole length on lamina length: cultivars with ' pigmented ' tubers*

Cultivar No.	*Name*	*Accn. No.*	*Mean* petiole length* $\bar{y}$ *cm*	*Mean* lamina length* $\bar{x}$ *cm*	*Regression of y on x b*	*S.E. of b*	*Corr. coeff. of y and x r*
9	' *Wild* '	03/57	12·0	14·8	+1·22	±0·46	+0·69
9	' *Wild* '	22/58	8·2	11·4	+0·11	±0·56	+0·07
10†	' *Sweet* '	05/58	6·2	9·6	−0·57	±0·59	−0·32
11	' *Oriental* '	40/57	3·6	7·7	+0·21	±0·16	+0·42
11	' *Oriental* '	39/57	3·5	7·2	−0·02	±0·36	−0·02
12	' *Wild Red* '	38/57	6·1	10·1	−0·43	±0·89	−0·17
13	' *Butterfly* '	26/57	10·2	11·0	+0·24	±0·67	+0·12
14	' *St Vincent Red* '	04/58	5·8	9·3	+0·70	±0·19	+0·79
15	' *Red Cane* '	06/56	5·4	9·4	+0·58	±0·16	+0·79
16	' *Moonshine* '	29/57	7·1	9·7	+0·79	±0·49	+0·49
Mean values			6·8	10·0	+0·28		+0·29

* Means based on ten measurements.
† Petioles pigmented only.
Association between cultivar means:
r_{yx} = +0·948
b_{yx} = 1·20 ±0·14

Having reached the stage of being able to distinguish the majority of useful cultivars on leaf characters an attempt was made to obtain a discriminant function to separate cultivars 10 and 11. The leaves of the ' Sweet ' are rather similar to ' Oriental ' except that the basal lobes of the former appeared a little more rounded and the blade a little longer.

The results are set out in *Table 5*.

Table 5. Discrimination between the ' Oriental ' and ' Sweet ' yam cultivars

	' Oriental '		Danish*	
	Means†	*Ranges*	*Means*†	*Ranges*
Length, L (cm)	7·16	6·2–8·0	7·69	6·2–9·1
Breadth, B (cm)	4·38	3·9–5·4	4·44	4·0–4·9
Angle, A (degrees)	76·9	20–122	103·6	55–135
$D_{LB} = -0{\cdot}06106L + 0{\cdot}67245B$			2·51612	
$D_{LBA} = -0{\cdot}01572L + 0{\cdot}65943B - 0{\cdot}00392A$			2·40087	

	' Sweet '				
	Means†	*Ranges*	*F* (1·18)	*Misclassification* %	% *S.E.*
Length, L (cm)	9·55	8·7–10·7	32·04	11	8·2
Breadth, B (cm)	6·60	5·9– 7·6	116·65	1·5	8·1
Angle, A (degrees)	84·9	55–112	13·32	34	24·3
$D_{LB} = -0{\cdot}06106L + 0{\cdot}67245B$	3·85505		56·90	1·3	—
$D_{LBA} = -0{\cdot}01572L + 0{\cdot}65943B - 0{\cdot}00392A$	3·86930		39·16	1·0	—

* A clone of the ' Oriental ' cultivar.
† Means based on ten measurements made at 5 to 6 months from planting.

From the results it is evident that lamina breadth is the most reliable diagnostic character. This fact was not evident in the field. Two discriminants were calculated, the best one involved length, breadth and angle, but even that did not reduce the chances of misclassification by very much over the use of the breadth alone. The angle was the most unreliable character.

The question next arises whether the differences exhibited by the leaves under cultivation conditions described in Trinidad will be displayed elsewhere. In the case of *D. gibbiflora* (section Enantiophyllum), quoted by Prain and Burkill (1930), differences in leaf shape produced in that species under sunlight and shaded conditions are marked. The effect of disease and/or adverse environment has already been shown with ' Coconut Lisbon ' and ' Horn ' which clearly never reached full development. It is subject to experiment therefore how applicable the measurements may be elsewhere.

TUBER VARIATION

The cultivars can be generally divided into those with pigmented and non-pigmented tubers and each of these two sections sub-divided into groups which have similar shapes and depths of tuber formation. A classification of tubers in this way cannot be hard and fast because of the variation caused probably primarily by the soil and rainfall. Burkill (1917) no doubt had a greater range of variability and therefore probably a rather fuller picture of the forms; here we have yams which have been already selected again with a consequent incomplete picture of the range. *Table 6* gives a series of groupings for the tubers and those in heavy type represent probably the truest positions using normal commercial cultivation in Trinidad.

It is interesting to note that during the first season ' Oriental ' was cultivated when conditions were dry and no tuber exceeded 22 cm in length whilst in the second and wetter season and under more fertile conditions many tubers were almost 30 cm. Under the dry conditions in Barbados

these tubers are usually quite shallow going. For the purposes of the table ' Deep going ' refers to tubers which are rarely under 30 cm long and usually about 45 cm, whilst ' Shallow going ' tubers rarely exceed 30 cm.

Figures 3 and *4* show the main forms which were all grown under similar environmental conditions in 1957 except for ' Sweet ' which was cultivated the following year.

Table 6. The tuber forms of D. alata *cultivars*

Tuber form or shape	*Outer cortex colour*	
	White to cream and occasionally pink	*Red to magenta*
Deep going and ridged	**' Wild '***	*' Wild '*
		' Butterfly '
Deep going and digitate with a long ' neck '	**' Long Finger '***	**' Wild Red '***
Deep going with few ' fingers ' and a long ' neck '	**' Bottleneck Lisbon '**	*' Wild Red '*
Deep going and cylindrical	**' Horn '†**	*' Red Cane '†*
Shallow to deep going and digitate with a short ' neck '	**' Ginger '***	*' St Vincent Red '*
		' Moonshine '*
		*' Butterfly '**
Shallow ' rooting ' with few ' fingers '	**' Hunte '**	*' St Vincent Red '*
	' White Lisbon '	
Shallow going, globular to ovoid sometimes cylindrical	**' Coconut Lisbon '†**	**' Oriental '†**
	' Barbados '†	
Shallow going, multiple tubers usually cylindrical	**' Sweet '**	*Not represented*

*Tubers thickly covered with roots.
† Tubers with very few roots.

VARIATION IN STORAGE

There are periodic shortages of yams in the eastern Caribbean particularly from July to November. It was therefore considered desirable to conduct a trial to obtain information on the variation in the loss of weight which occurs in the various cultivars during storage. Seven *D. alata* cultivars were selected for trial together with a commercially desirable cultivar of *D. esculenta* called ' Chinese '. The design was four randomized blocks, and each unit consisted of ten pounds of tubers.

Table 7. Yam storage trial conducted at the I.C.T.A. New Farm, 1958. *(Units stored—ten pounds of tubers; experiment begun on* 13/2/58, *nine days after harvesting and recorded on* 9/6/58, *eighteen weeks from harvesting)*

Cultivar No.	*Name*	*Mean percentage loss in weight*
2	*' Hunte '*	9·7
3	*' Bottleneck Lisbon '*	7·3
4	*' Ginger '*	7·5
6	*' Coconut Lisbon '*	11·3
8	*' White Lisbon '*	7·7
11	*' Oriental '*	21·6
16	*' Moonshine '*	23·2
	**' Chinese '*	24·6
	Mean	14·1

* ' Chinese ' is a cultivar of *D. esculenta*.
S.E. per ' plot ' ±2·795 or 19·8 per cent (21 d.f.).

The tubers were stored on wire racks in a darkened room at normal temperatures and humidities from 4/2/58 to 9/6/58. The percentage loss in weight from the tubers due to sprouting and moisture loss was recorded when all but one cultivar, ' White Lisbon ', had sprouted. The results as given in *Table 7* clearly show that the pigmented *D. alata* yams have a much poorer storage quality than the non-pigmented ones in the trial, while the most commonly grown ' White Lisbon ' is amongst the best. The ' Short Finger ', a good storing yam, of shallow-going habit seems to have been relegated to a position of little importance because the tuber is thickly covered with roots.

It is to be noted that all the tubers used in the trial were selected beforehand for absence of damage and there was no loss over the whole period of the experiment due to fungus or insect attack.

METHODS OF EFFECTING IMPROVEMENT IN THE CROP

The definition of the limiting factors in production and the formulation of objectives are of basic importance. Of the former the high cost of production by hand labour is a primary consideration, and therefore mechanization of the more expensive operations in growing would seem desirable. Secondly, prices of the tubers fluctuate widely in the eastern Caribbean markets, in particular due to periodic surpluses and shortages, caused by the absence of any very long storing cultivars, and the lack of very early and very late maturing varieties. These are the two basic problems of improvement which have many ramifications.

The operations involved in growing yams (Brown, 1931) are trenching, manuring the trenches, ridging, planting, weeding, staking and harvesting. The trenching and formation of ridges is easily accomplished mechanically on suitable terrain, and the actual planting does not appear to be expensive. Weeding can be costly but Falode (1958) has shown that weeding costs can be considerably reduced by the use of herbicides. Staking is fairly expensive and probably essential for very high yields (Burkill, 1920). For that reason it would seem desirable to determine whether stakes are necessary to obtain an economic yield with all the better shaped cultivars and if so to determine the optimum rate and height of staking required in terms of production costs. In Barbados, yams are not usually staked, but yields are generally lower which could be due to the drier conditions or several other factors.

The final and probably one of the most expensive operations is harvesting which is normally carried out by hand. An implement for harvesting has been designed (Barrett, 1958). It will lift 87 per cent of the I.C.T.A. commercial Lisbon crop undamaged. Tubers can be lifted which do not exceed twelve inches in depth which means that all except the heavily fingered and deeply ' rooted ' are harvested intact. Despite this it would still be desirable, given an adequate yield, to grow an ovoid tuber which is shallow rooting and which is less easily broken in harvesting, sacking and transport.

Burkill (1917) has pointed out that primitive man practised selection for shallow ' rooting ' in this species and the Caroline Island cultivar he describes closely resembles the ' Oriental '. This cultivar together with the ' Coconut Lisbon ' and ' Barbados ' are probably the most suited to mechani-

cal cultivation in the Caribbean. Of these three cultivars the ' Oriental ' would seem ideal except for its poor storage qualities, and its tendency sometimes to reach twelve inches or a little more in depth; but with closer spacing tuber size might be limited. The ' Coconut Lisbon ' appears to be virus infected and the ' Barbados ' is in extremely short supply at present.

' White Lisbon ' is high yielding and it may not be possible to achieve such a yield with a globular tuber cultivar. Those with deep going tubers, although high yielding, are obviously useless for economic production. As the tubers are produced from single pieces of perennial stem, which do not normally branch, yield can only be increased by increase in depth, by lateral spreading and digitation or by the formation of several tubers as in the ' Sweet '. ' White Lisbon ' appears to combine the features of high yield by only relatively shallow rooting and digitation and/or occasional twinning of the tubers.

From the aspect of possible breeding, crosses involving ' White Lisbon ', ' Barbados ' and ' Sweet ' would seem desirable, or interspecific crosses with *D. esculenta* the tubers of which are similar to those of *Solanum tuberosum*.

Fertility is infrequent in *D. alata* and of the clones examined at the I.C.T.A. no fertile ' White Lisbon ' has been found. Capsules are produced on ' Oriental ' and ' Wild ', and male and female clones of *D. trifida* exist, which species produces multiple tubers of excellent eating quality. Clearly any breeding would have to be preceded by a study of the floral biology and cytology of the species which would be likely to be very long term. It is necessary therefore to consider how the existing cultivars might be utilized to best advantage if variation is not extended by other means. A search should therefore be made for possible yield variants in the present population, for DAVIDSON and LAWLEY (1953) have shown that yield variation occurs in clones of *Solanum tuberosum*. With *Dioscorea* cultivars such a possibility would seem likely as they have been vegetatively propagated for such a long period.

Turning to the second aspect, that of availability, it has been shown by CHUKWUEKE (1956), that sprout inhibition can be brought about in ' White Lisbon '; this technique could probably be applied to the ' Oriental '. The variation in maturity is not marked and for that reason the possibility of growing out-of-season crops by the use of dormancy-breaking substances, which has been demonstrated experimentally by TERIBA (1958), with ' White Lisbon ', is particularly important.

To sum up, selection practised in the past has been remarkably successful in *D. alata* and it will only with difficulty be improved upon.

SUMMARY

The need and importance of a survey of West Indian *Dioscorea alata* cultivars is discussed. Sixteen cultivars are distinguished and a key and detailed descriptions of these are given. A table shows their distribution and vernacular synonyms in six West Indian Islands.

The results of a storage trial show statistically significant differences among certain commercially desirable ' alata ' cultivars and *Dioscorea esculenta*, and demonstrate that the ' Lisbon ' group possesses the best keeping quality.

It is pointed out in a discussion on methods of effecting improvement with this crop that the high yielding cultivars produce deeply forming or digitate tubers, which are often not amenable to mechanical harvesting. A possible solution is seen in the greater use of shallow and ovoid tuber forming cultivars, such as the ' Oriental ', ' Barbados ' and ' Coconut Lisbon '.

The conclusion is drawn that the potential usefulness of these cultivars could be partly exploited by the adoption of optimum spacing and mechanical harvesting. Also, by the use of a suitable sprout-inhibiting substance to improve storage qualities, and a dormancy-breaking substance to permit planting out of season, periodic shortages could be overcome. It is suggested that, as the yams described are relatively free from disease and many are high yielding, and as infertility is common, attempts at seedling improvement do not appear to be justified at present.

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Fertilizer Experiments With the Gros Michel Banana

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Although the banana plant has been grown commercially for more than half a century and is a staple food crop in many tropical countries, little information has been published regarding its response to fertilizers. In his book *The Banana*, Fawcett (1913) gives chemical analyses of certain varieties of banana and lists the results of fertilizer experiments carried out in Queensland, Australia, where types of fertilizer utilized and rates of application were based mainly on the results of these plant analyses. Fawcett's recommendation for the Jamaican soils then under banana cultivation was limited to increasing the organic matter by the use of farmyard manure. It is of interest, however, that he records at this early date, 1913, that sulphate of ammonia had been found to be a possible substitute for organic matter on banana cultivations in British Guiana. More recently Holmes (1930) described the fertilizer requirements of the Dwarf Cavendish banana grown under the intensive system of culture practised in the Canary Islands.

In 1940 Croucher and Mitchell published the results of fertilizer experiments with the Gros Michel banana in several agricultural zones of Jamaica. They did not perform experiments on the alluvial plains of the St Catherine and Vere districts of the south coast, where extensive fertilizer tests had been operated since 1930 by the Research Department of the United Fruit Company. Additional work in these areas was deemed unnecessary at that time, since the Company experiments were frequently observed by members of the Jamaican Government Agricultural Department, and all records were made available to them.

Apart from the work of Croucher and Mitchell, all work published on fertilizer experiments before 1940 was concerned with members of the Cavendish group of bananas. The large exporting areas of the West Indies, Central America and the northern part of South America then grew only the Gros Michel variety. Moreover, though bananas in most other parts of the world were generally cultivated on sedentary hillside soils which were dependent upon rainfall and usually partially eroded, the Central American cultivations were virtually confined to deep alluvial soils derived from several types of parent rocks, many of them irrigated for several months of the year.

Investigations of chemical fertilizers were started by the Research Department of the United Fruit Company in Central America in the year 1917, following an extensive soil survey by Dr Samuel C. Prescott (1918) of existing banana areas in Panama, Costa Rica, Honduras, Guatemala and

*The Tela Railroad Company is a subsidiary of the United Fruit Company and the experiments described in this paper were carried out by the U.F. Co., in Jamaica and Honduras under the direction of the author. Though the experiments to be described go back to 1930, the information has only just been released for publication by the Company.

Colombia and work in the Motagua river valley of Guatemala by Dr Lewis Knudson, at that time head of the department of Plant Physiology at Cornell University. Most of these early experiments were designed primarily to observe the effect of improved nutrition of the Gros Michel banana in relation to its resistance to *Fusarium oxysporum* f. *cubense*. This fungus is the organism responsible for Panama disease which, then as now, was the principal source of loss of production in the cultivation of the Gros Michel banana. Although these efforts to improve nutrition were not successful in reducing the devastating effects of the disease, a great deal of valuable information was accumulated regarding the chemical and physical qualities of those soils which appeared to be more resistant to *Fusarium oxysporum* f. *cubense*, and upon which the profitable life of a cultivation, when planted to the Gros Michel variety, extended over several years following planting.

Work along similar lines was continued in the Ulua Valley of Honduras in the late nineteen-twenties and early thirties by Dr N. J. Volk and his associates. Included were fertilizer experiments designed to test the effects upon yield of the common inorganic fertilizers.

In Jamaica in 1930, the Research Department of the United Fruit Company established an agricultural experiment station at Cedar Grove Farm in the St Catherine district, an arid area of alluvial soil on the south coast of the island. This area had been under the cultivation of Gros Michel bananas for many years. Soil fertility, initially high, had declined over the years and this was reflected in decreased production both in bunch size and in the length of the individual fruits. WARDLAW (1929) had previously drawn attention to the rapid deterioration of some virgin soils in the Caribbean area. Work at this station was continued over the period 1930 to 1942 when war conditions resulted in fertilizer shortages and a general but temporary decline of interest in the cultivation of bananas. By 1942, Panama disease had made considerable progress and the island industry was considering the substitution of disease-resistant varieties. Subsequently Lacatan was adopted and post-war fertilizer experiments with bananas in Jamaica have been wholly concerned with this variety (Dep. Agr. Jamaica, 1950–).

Investigations of the nutritional requirements of the Gros Michel variety in Central America had been carried on spasmodically during the period 1930 to 1947. From these studies, as well as from the Jamaican tests and from the earlier work of Knudson and Volk, it appeared that a thorough study of fertilizer effects on the alluvial lands of Central America was desirable. In 1948, extensive tests of the major fertilizer elements were designed for soils of the two main banana areas of the Republic of Honduras, the Ulua and the Chamelecon river valleys. These field experiments have been continued ever since that time and, more recently, similar work has been developed on the west coast of Guatemala, the Atlantic coast of Panama and the Sevilla district of Colombia.

GENERAL REMARKS

Preliminary investigations in Jamaica were undertaken to correct a condition which already existed, and were, therefore, in the nature of a crash programme. FISHER's (1926) earlier mathematical approaches to

agricultural research problems by this time had influenced experimental design. All tests were therefore replicated many times and the experiments repeated in several different areas. However, because of the nature of the particular problem, and because all fruit in the experimental plots was later harvested and shipped, many of the earlier experiments were of a systematic design. Trained personnel to carry out the experiments was not available and the fertilizer applications and recording often had to be done by field labour whose technical knowledge was extremely limited, whose reasoning was direct and not abstract, and to whom the irregular patterns of randomized treatments were confusing. The relative advantages of systematic and random arrangements have been the subject of considerable differences of opinion for many years among agronomists responsible for projecting limited experimental data to field application [see e.g. Gossett (1937) and Salmon (1953)]. In working with untrained personnel in the tropics, the disadvantages of possible errors in fertilizer application and recording appeared to outweigh the advantages of randomization, particularly where plot replication could be substantially increased over that normally utilized in field experiments of this type. Extra care was taken to avoid confusion both in recording and in fertilizer application, by utilizing coloured plot markers and fruit tags so that all treatments in any one test were marked with the same colour.

Later work in Honduras, where better facilities were available, has been carried out using more orthodox methods, and the results subjected to statistical analysis. Because the results in both Jamaica and Central America follow the same general trend, and because the general outline of the Central American experiments was based upon the results obtained in Jamaica, these earlier tests have been included in the general discussion of results. However, no attempt has been made to analyse the earlier data statistically. The results of the early experiments with nitrogen applications later withstood the test of expansion to very large areas and became the basis of standard field-practice in company farms.

In the experiments described, records were usually obtained, at monthly intervals, of lineal growth to the point of emergence of the last leaf of the mother plant. Plants were pruned to a single follower and the record of growth was continued on this follower as soon as the mother plant had reached the fruiting stage and thus ceased to produce leaves. Fertilizer applications were weighed, packaged and labelled at the storage shed for each sub-plot, using tags of the same colour as the treatment plot markers. By this method, mistakes due to wrong applications were avoided, and through packaging for small unit areas, uniformity of application was achieved over the entire treated area. Records were also obtained of the number of hands per stem, and, in most experiments, the weight of the bunch when harvested. In this manner, production per acre could be obtained, either as bunches of a certain size, or total weight, or both. The relationship of weight per bunch to the number of hands is usually an index of quality, since if cut at the same grade, increased weight per hand denotes increased finger length, which in turn improves general appearance.

In Central America the term ' grade ', used in discussing fruit samples, refers to the degree of maturity at which the fruit was cut. The period

may vary from 75 days to 130 days or more from shooting and is of course influenced somewhat by climatic conditions at the time the fruit is developing. The ' grade ' cut varies with the expected time of shipment under refrigeration. The degree of least maturity is ' light three-quarter grade ' and that of greatest maturity ' full grade '. The weight of the bunch depends a great deal upon the degree of maturity so that for valid weight comparisons, samples of bunches of equal ' grade ' must be utilized.

In Jamaica and the West Indies generally, the word ' grade ' is used to define the number of hands per bunch.

EXPERIMENTS IN JAMAICA, 1935 TO 1942

The earliest tests were comparisons of nitrogen, potash and phosphorus, used alone and in combination, with check areas receiving no fertilizer. These experiments also included farmyard manure at various rates, a bat guano found in local caves, and a commercial fertilizer, Ammophos, which had already received some attention locally as a fertilizer for sugar-cane. These tests showed that organic manures and those containing nitrogen increased growth substantially but that the other elements caused little visible response. The cost and relative scarcity of organic manures appeared to preclude their use on a commercial basis, and they were not further investigated.

The first recorded test with nitrogen, potassium and phosphorus was carried out at Watson Grove Farm in the St Catherine district of Jamaica in 1933. It consisted of nine single rate treatments; the eight possible NPK combinations at two levels (0, 1); and Ammophos applied at the equivalent nitrogen rate. Plots were of three rows, each of ten banana mats, and the treatments were replicated five times. The plots were not separated by guard rows—an error which was corrected in subsequent experiments. Nitrogen was applied in twelve monthly applications as nitrate of soda at the rate of 86 pounds of nitrogen per acre per annum. Phosphorus was applied as 16 per cent superphosphate four times a year at the rate of 64 pounds phosphorus pentoxide per acre per annum. Potassium was applied as sulphate of potash four times a year at the rate of 200 pounds of potassium oxide per acre per annum. Ammophos containing 16·5 per cent nitrogen and 20 per cent phosphorus pentoxide, was applied at monthly intervals

Table 1. Record of fruit produced, Watson Grove Farm, St Catherine district January 1933 to December 1937. Total production per acre and mean weight per bunch (full-three-quarter grade)

Fertilizer treatment	*Tons per acre per annum*	*Mean weight per bunch in pounds*	*Bunches per acre per annum*
Check—No fertilizer	9·20	58·94	313
Nitrogen	10·66	61·34	348
Nitrogen+phosphorus	10·82	61·82	350
Nitrogen+potassium	11·09	63·55	349
Nitrogen+phosphorus+potassium	11·25	63·67	354
Phosphorus+potassium	9·27	60·32	308
Potassium	8·83	59·19	299
Phosphorus	9·12	58·94	310
Nitrogen+phosphorus as 16·5/20 Ammophos	10·42	61·50	339

at the rate of 540 pounds per acre per annum. This supplied 89 pounds of nitrogen per acre and 108 pounds of phosphorus pentoxide.

Results obtained over a four-year period are given in *Table 1*. They show substantial increases in bunches per acre and total weight per acre as a result of the use of nitrogen, with further smaller increases when potassium was included. Weight per stem also follows the same trend.

The four most promising treatments at the end of 1933 were extended in 1934 to 22 different production areas located on 15 different farms in the St Catherine district. Each of the four treatments, adequately protected by guard rows, was tested on 100 banana plants at each location. Records were confined to measurements of lineal growth, number of bunches of fruit produced, and the size of each bunch as determined by the number of hands. Since the experimental areas were widely scattered it proved impracticable in this instance to weigh the fruit. The plant populations varied from 360 to 444 plants per acre. There were 9 plots spaced 14×14 feet double planting, 8 plots spaced 11×11 feet single planting, also 5 plots spaced $10{\cdot}5 \times 10{\cdot}5$ feet. In this case nitrogen, applied as nitrate of soda at monthly intervals, varied from 86 to 107 pounds per acre per annum, depending upon the population utilized in the different replicates. Phosphorus, as 16 per cent superphosphate, applied four times per year, varied from 64 to 79 pounds phosphorus pentoxide per acre per annum; potassium, as sulphate of potash, applied in this case once a year, varied from 200 to 247 pounds potassium oxide per acre per annum. A summary of growth and fruiting performance, covering the period February 1934 to June 1938, is given in *Table 2*. The growth statistic is based upon a total of 840 804 individual growth measurements, and the fruiting data upon the production from 8 800 banana mats. The data indicated that, in the St Catherine area generally, fruiting or growth responses of an economic nature could not be expected from the use of phosphorus or potassium in addition to nitrogen. This was on soils where the potassium content varied from 150 to 300 parts per million of soil and the phosphorus content from 100 to 600 parts per million.

Experiments with two levels of nitrogen, applied as nitrate of soda at monthly intervals, were meanwhile being carried out in another area at Cedar Grove Experiment Station. This design was a series of 3×3 latin squares arranged systematically to give a total of 21 replications. Plot size was 0·1 acre, each plot consisting of 36 banana plants. Rates of application were 2 ounces and 4 ounces per plant per month. These gave 86 pounds and 172 pounds of nitrogen per acre per annum, respectively.

Table 2. Complete fertilizer plots, St Catherine district, Jamaica. Summary of growth and fruit production, 22 acres, February 1934 to June 1938

Fertilizer treatment	*Mean monthly lineal growth per plant in feet*	*Total production, bunches per annum*	*Mean number of hands per stem*
Nitrogen	0·67	395	9·19
Nitrogen + potassium	0·68	393	9·23
Nitrogen + phosphorus	0·67	393	9·18
Nitrogen + phosphorus + potassium	0·67	390	9·22

Table 3. Record of fruit produced, Watson Grove Farm, St Catherine district, July 1933 to December 1937. Total production per acre and mean weight per bunch (light three-quarter grade)

Fertilizer treatment	*Tons per acre per annum*	*Mean weight in pounds per bunch*	*Bunches per acre per annum*
No fertilizer	5·74	40·48	285
2 ounces nitrate of soda per plant monthly 86 pounds N *per acre annually*	8·77	45·68	384
4 ounces nitrate of soda per plant monthly 172 pounds N *per acre annually*	9·11	45·51	400

Data of fruit production, recorded over the period July 1933 to December 1937, are summarized in *Table 3*. They show approximately 52 per cent increase in total weight per acre produced for the first level of nitrogen, with a further 6 per cent for the second level. Weight per bunch shows a 12 per cent increase for both levels. Bunches per acre show 34 per cent increase for the first level of nitrogen and 41 per cent for the second level of nitrogen. In this experiment fruit was cut at light three-quarter grade, the degree of maturity which permits shipments to carry fifteen days or more under proper refrigeration without undue ripening. Consequently, individual bunch weights are substantially less than for the full three-quarter grade of *Table 1*, used for carrying approximately six days under refrigeration. Subsequent investigation of the effect of nitrogen levels upon individual bunch weights in Honduras, using only the full three-quarter grade, indicate that differences in bunch weights due to nitrogen levels are probably greater in the more mature fruit. Different grades of fruit were cut in the different experiments because all fruit was shipped in normal cargoes and both the American and European markets were being supplied during this period from this production centre. Since the journeys in those days occupied from six to fifteen days or more, depending upon the ultimate destination of the cargo, it was necessary to vary the degree of maturity at which the fruit was cut. Thus the fruit from different areas was cut only for the different markets, in this manner avoiding gross variations in weight in any one experiment due to grade. This system of experimentation possessed the great advantage that relatively large areas involving large numbers of individual bunches could be used for test without losing farm revenue.

Nitrate of soda was utilized in these earlier experiments because it was easily obtainable during this period. Sulphate of ammonia was also readily available, and comparisons with nitrate of soda, on an equal nitrogen basis, demonstrated that it was equally efficient as a banana fertilizer. However, even on the heavily buffered soils of St Catherine, where the mean pH values encountered were usually 8·0 or above, use of sulphate of ammonia over the four-year period had reduced this to 7·4. Since, in general, the areas most resistant to Panama disease were those of high pH, the use of sulphate of ammonia was not recommended and other types of nitrogen carriers which did not leave acid residues were sought. Trials of four of these were carried out at Watson Grove Farm over the period April 1937 to December 1939. The experimental design was four latin squares each with five treatments, totalling 20 replicates of each treatment.

The four nitrogen carriers tested were nitrate of soda, nitrochalk, urea and calcium cyanamide. The application was 86 pounds of nitrogen per acre annually. For convenience of handling, nitrate of soda and nitrochalk were applied at monthly intervals, while the more concentrated calcium cyanamide and urea were applied at six-week intervals. The results of

Table 4. Five different nitrogenous fertilizers at Watson Grove Farm, St Catherine district, Jamaica. 86 pounds of nitrogen per acre per annum. Total production per acre and mean weight per bunch, 33 months from planting, April 1937 to December 1939 (Three-quarter grade)

Treatment	*Tons per acre per annum*	*Mean weight per bunch in pounds*	*Bunches per acre per annum*
Check—no fertilizer	7·93	48·92	322
Nitrate of soda	9·58	54·19	364
Nitrochalk	9·02	52·85	341
Urea	9·23	52·26	353
Calcium cyanamide	8·91	52·45	338

these tests are given in *Table 4*. The grade of fruit cut was three-quarters, at that time favoured for the Canadian market. It will be observed that substantial increases in production, both in number of bunches and in total weight, were obtained.

The frequency with which the non-leaching types of nitrogenous fertilizers need to be applied for maximum efficiency was also investigated using calcium cyanamide. The experimental design was a multiple 4×4 latin square, using 119 pounds of nitrogen per acre annually, on a population of 360 plants per acre. This was equivalent to a monthly application of 2 ounces of calcium cyanamide per plant. Four different frequencies were tested, i.e. twelve, six, four and three times per year, corresponding to one-, two-, three- and four-monthly intervals. The fruiting performance over the four years of the experiment (January 1935 to December 1938) is summarized in *Table 5*. A slight deterioration in fertilizer efficiency as the cycle was lengthened is indicated by these data.

Table 5. Calcium cyanamide on four application cycles—Equal amounts of nitrogen (119 pounds per acre per annum). Total production per acre and mean weight per bunch—48 months from planting. January 1935 to December 1938 (Full-three-quarter grade)

Treatment	*Tons per acre per annum*	*Mean weight per bunch in pounds*	*Bunches per acre per annum*
2 ounces per plant monthly	11·25	64·43	349
4 ounces per plant bimonthly	11·07	63·78	347
6 ounces per plant at three month intervals	10·94	63·82	343
8 ounces per plant at four month intervals	10·70	63·99	334

The use of the more common minor elements was also tested in the St Catherine district. Iron, manganese and boron were applied to bananas receiving 86 pounds of nitrogen per acre as nitrate of soda, 64 pounds of phosphorus pentoxide as superphosphate and 200 pounds of potassium oxide as sulphate of potash. Iron was applied as ferrous sulphate, manganese as

manganous sulphate and boron as sodium borate. In each case 4 ounces was applied to each banana plant. The spacing was 11 × 11 feet and the population 350 banana plants per acre. Thus, the amount of iron applied was 18 pounds per acre; manganese applied was also 18 pounds per acre and boron, 10 pounds per acre.

Table 6. Record of fruit produced, Pumpkin Ground Farm, March 1937 to December 1939. Iron, manganese and boron plots 34 months from planting. Total production per acre and mean weight per bunch (three-quarter grade fruit)

Treatment	*Tons per acre per annum*	*Mean weight per bunch in pounds*	*Bunches per acre per annum*
Check—no treatment	7·80	50·45	292
Ferrous sulphate	8·20	51·05	303
Manganous sulphate	7·41	49·10	285
Sodium borate	6·87	45·84	283

The rates chosen were purely arbitrary and exploratory; no indication of minor element deficiency had been observed in the appearance of the plants themselves. Experimental design was a multiple 4 × 4 latin square with 16 replications; fruit was cut at the three-quarter grade. Details of fruiting performance to December 1939, a period of 34 months from the time of planting, are given in *Table 6*. It appears from these data that boron suppressed growth somewhat, and also reduced the weight of the bunch. Possibly manganese produced a similar but somewhat lesser effect. In the later experiments in Honduras, these two elements also appeared to depress yield even though boron applications in the latter were reduced to 50 pounds per acre of sodium borate, or about 5 pounds per acre of boron.

In addition to the experiments described, a further test of large application of sulphate of potash was started early in 1940, in combination with the usual nitrogen applications. Ten pounds of sulphate of potash was applied to each banana mat as a band application. The planting distance was 13·5 feet square and two plants were grown per mat. Thus, the rate of application was 2 390 pounds per acre, supplying roughly 1 200 pounds per acre of potassium oxide. At the end of October 1941, no difference in total production or fruit size could be observed and the test was abandoned.

During the operation of all these experiments, observations were made for possible influences of the various treatments upon the initial infection and spread of Panama disease. After 1935, when *Cercospora* leaf spot made its first appearance in Jamaica, these observations were extended to this disease also. No differences were apparent in Panama disease or leaf spot incidence between treated and check areas; i.e. there was no evidence to support the theory that disease severity in the case of these two plant diseases can be lessened by the improved nutrition of normal plants using the common macro and micro chemical elements.

HONDURAS EXPERIMENTS, 1948 TO 1951

By 1948, although bananas had been growing in many localities in Honduras for 20 years or more, fertilizing had been limited to occasional

applications of nitrogen to problem areas. Usually these were farms where insufficient drainage or windstorm damage had reduced the normal shade canopy and permitted the entry of grass. Such experiments as had been conducted were designed to overcome this particular problem and no continuous fertilizing had been practised. By the end of 1947, following several years of more than average windstorm damage, the fruit weights and total production had fallen substantially. The obvious approach was application of suitable fertilizers and experiments were designed and laid out in the two soil types predominating in the area. At Mopala farm, on the banks of the Ulua river, a silt loam soil, many feet deep, was chosen as representative of this general area. At Guaruma farm, on the banks of the Chamelecon river, a deep light clay soil was chosen. Later, when it became probable that flood fallowing might be of some practical use in the control of Panama disease (Stover *et al.*, 1953; Stover, 1956), an area of recently flooded light clay soil was chosen at Copen farm also on the Chamelecon river.

Two main types of experiments were designed, one utilizing four levels of nitrogen and the other utilizing potassium and phosphorus in conjunction with nitrogen. An additional test, utilizing five different types of nitrogen carriers at one level of nitrogen, was included both at Mopala and at Guaruma. The nitrogen tests were designed as randomized blocks with four replications and the complete fertilizer tests as a multiple latin square with 16 replications. Adequate separation by guard rows of 50 to 100 feet was supplied in all these tests, based upon previous experience in Jamaica. Also, in view of the fact that Panama disease was present in the areas at Mopala and Guaruma at the commencement of the experiment, all main plots were sub-divided into 50×100 feet subplots and recorded separately. Nitrogen was applied, as nitrate of soda, monthly. Phosphorus was applied, as superphosphate and potassium as sulphate of potash, four times a year.

The general programme of experimentation followed that used successfully in Jamaica. Studies of nitrogen levels and complete fertilizers and minor elements proceeded simultaneously and the experimental areas were spread geographically to reduce the hazard of heavy blowdown losses. Also, a series of demonstration-type tests, using different levels of nitrogen and also potassium and phosphorus in conjunction with one level of nitrogen, was put in on several existing farms. Total area involved was 846 acres, of which 589 were demonstration plots and 257 were plots upon which detailed records of growth and production were secured. Of the latter, 100 acres were on Ulua silt soils and 157 upon Chamelecon clays. The whole experimental area was roughly two per cent of the total area in banana production in the Honduras division at that time; that part on which detailed records were kept represented 0·63 per cent. The total number of bananas upon which detailed records were secured during 1949 to 1951 was 265 817. Of this number, 160 777 were from the Chamelecon clays and 105 040 from the Mopala area of Ulua silt. Of the Chamelecon total, 56 018 stems were recorded from an area of Chamelecon clay replanted after being subjected to flood fallowing in an effort to control Panama disease (Stover *et al.*, 1953; Stover, 1956).

Fruit shipped amounted to 60 per cent of total experimental production and farm losses to 35 per cent. At the time the experiments were terminated, 5 per cent of the fruit remained unharvested.

As with the Jamaican tests, lineal growth was measured at monthly intervals on all plants. This supplied an excellent forecast of subsequent fruiting performance (see *Tables 7* and *14*). In a few months it became obvious that little difference in growth could be expected from either potassium or phosphorus or from the minor elements manganese, boron, iron and zinc. Increases due to nitrogen ranged from 15 to 37 per cent with a further 2 per cent increase in some areas where potassium and phosphorus were included. The latter difference, although most probably real, was not statistically significant at a probability of 5 per cent. Mean monthly growth for the four levels of nitrogen utilized over the period January 1949

Table 7. Mean monthly growth per plant in feet—July 1948 to December 1951, Chamelecon and Ulua Valleys—Republic of Honduras

Fertilizer treatment	*Guaruma plots*	*Mopala plots*
Check—no fertilizer	0·87 ± 0·015*	0·89 ± 0·016*
64 pounds N *per acre per annum*	0·99 ± 0·020	1·03 ± 0·014
128 pounds N *per acre per annum*	1·10 ± 0·016	1·13 ± 0·017
192 pounds N *per acre per annum*	1·14 ± 0·016	1·22 ± 0·019

* Standard error of mean.

Table 8. Experiments in Honduras, 1949–51. Growth rates (feet per month) for NPK *experiments (left) and for various levels of potassium oxide and phosphorus pentoxide, each with standard dressing of* N *(right)*

Treatment	*Honduras*			*Copen plots only*			
	Guaruma	*Copen*	*Mopala*	K_2O	*Growth*	P_2O_5	*Growth*
Check	0·91 ± 0·029*	1·08 ± 0·050	0·94 ± 0·038	200	1·33	40	1·31
N	1·10 ± 0·035	1·30 ± 0·047	1·12 ± 0·039	400	1·31	80	1·34
NK	1·10 ± 0·036	1·30 ± 0·047	1·14 ± 0·041	600	1·29	160	1·33
NP	1·10 ± 0·035	1·32 ± 0·049	1·12 ± 0·024	800	1·29	320	1·29
NPK	1·12 ± 0·034	1·32 ± 0·047	1·13 ± 0·024	1600	1·29	640	1·31

* Standard error of mean.

to December 1951, is shown in *Table 7* and for the complete fertilizers in *Table 8*. In the Copen plots, varying rates of potassium and phosphorus were applied. Growth rates in this area have also been tabulated according to the amount of potassium or phosphorus applied in conjunction with one level of nitrogen. These are included in *Table 8*. None of these differences is statistically significant. The Copen plots, recently replanted, showed faster growth than the older ' ratoonages '.

The effects upon growth of the minor elements, applied in conjunction with nitrogen, are shown in *Table 9*. During the nineteen months they were under observation no differences were apparent. Here again this was a young ' plantilla ', or plantation, growing upon an area previously flood fallowed. Growth rates are therefore substantially greater than in an old ' ratoonage '.

Where different levels of nitrogen were applied alone, growth was increased as the quantity applied became greater. The first 64 pounds produced a

15 per cent increase on both soil types observed. The second 64 pounds produced a further 12 per cent increase and the third 64 pounds a further 5 per cent on Guaruma clay and 10 per cent on Mopala silt loam. These increases in rate of growth were only partially reflected in increased size of

Table 9. Experiments in Honduras, June 1950 to December 1951. Chamelecon Valley. Mean monthly growth in feet—Minor elements test

Fertilizer treatments	*Copen plots*
Nitrogen	1·51 ± 0·070*
Nitrogen plus manganous sulphate	1·51 ± 0·069
Nitrogen plus sodium borate	1·49 ± 0·071
Nitrogen plus ferrous sulphate	1·51 ± 0·072
Nitrogen plus zinc sulphate	1·50 ± 0·073

* Standard error of mean.

plant. Height of the plant at the time it produced its fruit was increased in all cases by the addition of nitrogen and the increase was greater, the greater the amount of nitrogen applied. However, increase in lineal growth was approximately 15 per cent for the first level of nitrogen, whereas increase in shooting height was increased only 4·5 per cent at Guaruma and 8·0 per cent at Mopala. The increase in growth for the third level of nitrogen was 32 per cent at Guaruma and 37 per cent at Mopala. The increase in shooting heights was 9·5 per cent at Guaruma and 12·5 per cent at Mopala. Thus, only a portion of the increased growth is accounted for in height increase and the remainder demonstrates itself in earlier shooting.

Table 10. Experiments in Honduras, Chamelecon and Ulua Valleys, January 1949 to December 1951. Height in feet of plants when fruiting

Fertilizer treatment	*Guaruma plots*	*Mopala plots*
Check—no treatment	16·21 ± 0·026*	16·52 ± 0·033
64 pounds N per acre per annum	16·94 ± 0·027	17·84 ± 0·028
128 pounds N per acre per annum	17·56 ± 0·027	18·61 ± 0·028
192 pounds N per acre per annum	17·74 ± 0·029	18·59 ± 0·030

* Standard error of mean.

Table 11. Experiments in Honduras, Chamelecon Valley, January 1949 to December 1951. Height in feet of plants when fruiting

Fertilizer treatments	*Guaruma plots*
Check—no fertilizer	16·97 ± 0·042*
Nitrogen	17·81 ± 0·036
Nitrogen + potassium	17·84 ± 0·038
Nitrogen + phosphorus	17·67 ± 0·038
Nitrogen + potassium + phosphorus	17·86 ± 0·038

* Standard error of mean.

Shooting heights at Guaruma and Mopala for the four different levels of nitrogen utilized are shown in *Table 10*. Where potassium and phosphorus have been added to nitrogen at 144 pounds per acre, no difference is apparent in the shooting heights (see *Table 11*).

One effect of nitrogen fertilizer has been to increase the maturing period of the fruit. As shown in *Table 12*, maturing period was lengthened in all cases; and the increase became greater as the amount of nitrogen applied increased. The differences are statistically significant at a probability of 1 per cent. Potassium and phosphorus, either alone or in combination, have apparently exerted no influence over this growth phenomenon, as is shown in *Table 12*. It should be emphasized that this does not actually

Table 12. Experiments in Honduras, January 1949 to December 1951. Days from flowering to maturity. Chamelecon and Ulua Valleys. Fruit cut at full three-quarter grade

Treatment	*Guaruma plots*	*Mopala plots*
Check	98·54	99·90
N	104·39	102·67
NK	103·94	102·17
NP	104·42	102·35
NPK	103·82	102·71
*LSD P 0·05**	1·83	1·52
P 0·01	2·41	1·99
Check	99·42	101·02
*64*N	103·28	106·19
*128*N	104·13	105·97
*192*N	106·05	107·37
*LSD P 0·05**	1·12	1·26
P 0·01	1·48	1·66

* Least significant difference at 5 per cent and 1 per cent levels.

Table 13. Experiments in Honduras, January 1949 to December 1951. Chamelecon and Ulua Valleys, Republic of Honduras. Mean fruit weight increase per day in pounds

Treatment	*Guaruma plots*	*Mopala plots*
Check	0·68	0·86
64 pounds N *per acre*	0·72	0·90
128 pounds N *per acre*	0·77	0·95
192 pounds N *per acre*	0·78	0·94
Check	0·74	0·93
Nitrogen	0·77	0·99
Nitrogen+potassium	0·76	1·01
Nitrogen+phosphorus	0·77	1·00
Nitrogen+potassium+phosphorus	0·77	1·00

demonstrate a slower growth for the nitrogen plots. On the contrary, if the mean weight of the fruit is divided by the mean maturing period in days, it is apparent that the weight increase per day has been substantially improved. These mean daily increases in fruit weight over the period January 1949 to December 1951 are shown in *Table 13*. They reveal a maximum of 14·7 per cent at Guaruma and 10·2 at Mopala. These differences are for nitrogen only; potassium and phosphorus caused no such change.

In the cultivation of bananas, a perennial crop, growth is a continuous process and exerts a tremendous influence over yield. The faster the ratoons follow one another, the greater the number of bunches produced in a given area in any given period. In the experiments described here, the maximum improvement in production effected by nitrogen fertilizers demonstrated itself by increasing the number of stems produced 25·8 per cent at Guaruma and 25·3 per cent at Mopala and by increasing the mean weight of the bunch 23·0 per cent at Guaruma and 16·8 per cent at Mopala. Fruit size, as demonstrated by the number of hands, has also been increased by a maximum of 17·8 per cent at Guaruma and 25·9 per cent at Mopala over the three-year period during which fertilizers were applied.

Table 14. Experiments in Republic of Honduras, January 1949 to December 1951. Chamelecon and Ulua Valleys—Guaruma and Mopala plots. Fruit production per acre

Fertilizer treatment	*Guaruma plots*		*Mopala plots*	
	Bunches produced per annum	*Per cent production lost*	*Bunches produced per annum*	*Per cent production lost*
Check	401	42·2	434	30·2
*64*N	444	42·8	462	31·5
*128*N	500	43·6	491	33·0
*192*N	507	41·6	544	32·8
*LSD P 0·05**	44	3·46	54	5·81
0·01	63	4·98	78	8·37
Check	458	45·4	440	27·2
N	510	46·6	497	30·0
NK	516	47·4	495	34·2
NP	494	47·1	501	30·0
NPK	504	48·7	505	33·8
*LSD P 0·05**	19	1·81	19	3·14
0·01	24	2·39	25	4·18

* Least significant difference at 5 per cent and 1 per cent levels.

The influence of rate of growth in increasing bunch yields is demonstrated in the production data. These, together with losses, are shown in *Table 14* for both the Guaruma and Mopala plots. Total production of bunches increased steadily as the nitrogen applications became heavier. Losses accounted for roughly 43 per cent at Guaruma and 32 per cent at Mopala. In the latter area, some protection against wind damage was effected by the use of bamboo props.

The effects upon bunch production of potassium and phosphorus used in conjunction with nitrogen are also shown in *Table 14*. At Guaruma the maximum increase over the check area was 12·7 per cent for the nitrogen and potassium combination. The value for nitrogen alone was 11·4 per cent. At Mopala the maximum increase over the check area was 14·0 per cent for the nitrogen and phosphorus combination. Here the value for nitrogen alone was 13·0 per cent. These differences are not statistically significant.

No reduction in losses occurred where potassium and phosphorus were applied. From time to time generalized statements appear that potassium or phosphorus is responsible for more robust growth habits and superior root development. The extent to which these elements affect the growth of the banana plant, when grown in these two soil types, was obviously insufficient to reduce the effects of wind damage or to prevent collapse of the pseudostems as occurs in ' doubling ' (when the main stalk doubles over, usually in dry weather, as a result of carrying a heavy bunch of fruit). Neither has the use of complete fertilizers reduced the spread of Panama disease, or greater total production would be apparent in the treatments receiving complete fertilizers. Subsequent more careful studies of this phase of fertilizer use, where the range of both potassium and phosphorus has been extended, and many different combinations utilized in conjunction with one level of nitrogen, have confirmed these earlier tests both in regard to losses and also Panama disease activity.

In *Tables 15* and *16* the mean weight per stem, and total weight shipped per acre after farm losses, are shown for both the Guaruma and Mopala plots. Nitrogen alone at varying levels and nitrogen at one level, utilized

Table 15. Experiments in Honduras, January 1949 to December 1951. Chamelecon and Ulua Valleys—Guaruma and Mopala plots. Mean weight per bunch and weight per acre shipped

Treatment	Guaruma plots		Mopala plots	
	Mean weight per bunch in pounds	*Tons shipped per acre per annum*	*Mean weight per bunch in pounds*	*Tons shipped per acre per annum*
Check—no treatment	66·87	6·98	87·41	12·12
64 pounds N *per acre*	72·73	8·14	96·43	14·72
128 pounds N *per acre*	79·37	10·02	100·64	15·47
192 pounds N *per acre*	82·25	10·75	102·09	17·34
*LSD P 0·05**	0·75	1·18	0·79	1·97
0·01	0·98	1·69	1·04	2·83

* Least significant difference at 5 per cent and 1 per cent levels.

Table 16. Experiments in Honduras, January 1949 to December 1951. Chamelecon and Ulua Valleys—Guaruma and Mopala plots. Mean weight per bunch and weight per acre shipped. (Full three-quarter grade)

Treatment	Guaruma plots		Mopala plots	
	Mean weight per bunch in pounds	*Tons shipped per acre per annum*	*Mean weight per bunch in pounds*	*Tons shipped per acre per annum*
Check—no fertilizer	70·98	7·99	93·61	13·47
Nitrogen	79·37	9·49	102·09	16·39
Nitrogen+potassium	78·72	9·37	103·95	15·70
Nitrogen+phosphorus	79·36	9·12	102·97	16·67
Nitrogen+potassium+phosphorus	79·66	9·06	102·78	15·75
*LSD P 0·05**	1·03	1·37	0·99	2·22
0·01	1·35	1·82	1·30	2·97

* Least significant difference at 5 per cent and 1 per cent levels.

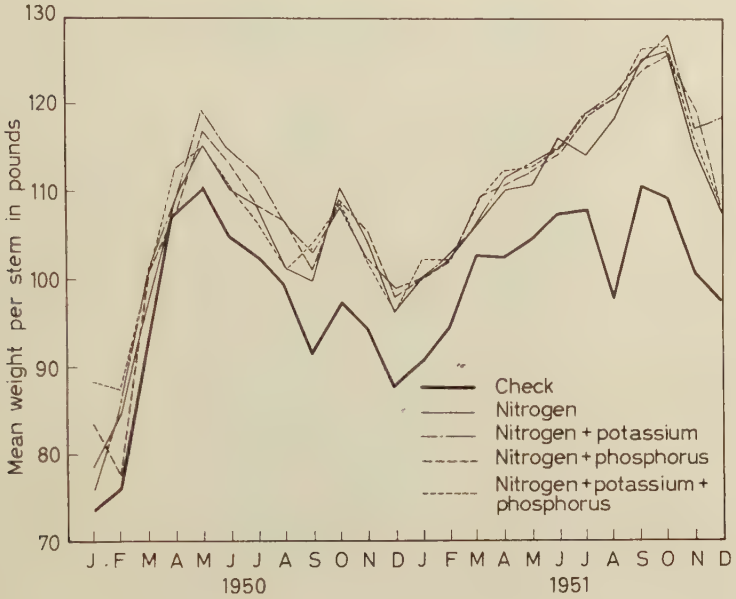

Figure 1. Mopala NPK *experiments 1950–1; monthly trends of bunch weights*

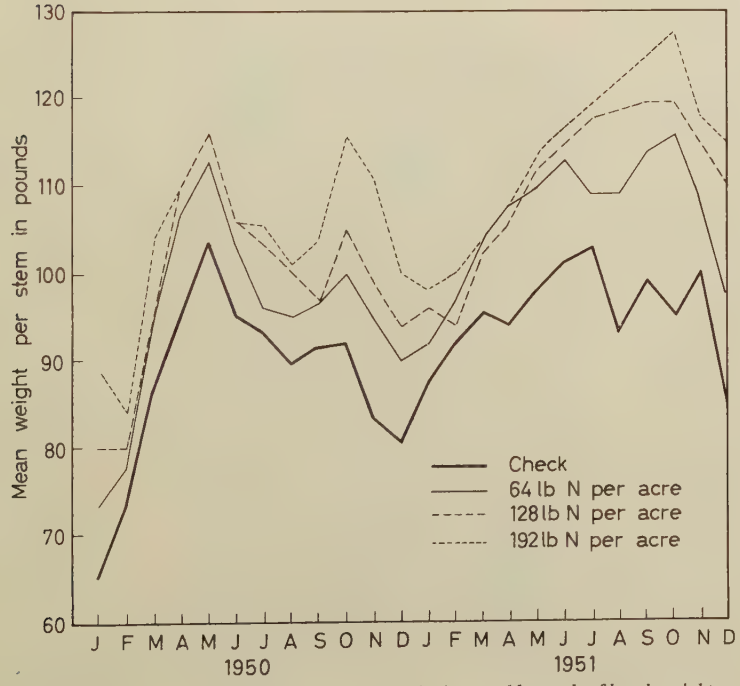

Figure 2. Mopala nitrogen experiments 1950–1; monthly trends of bunch weights

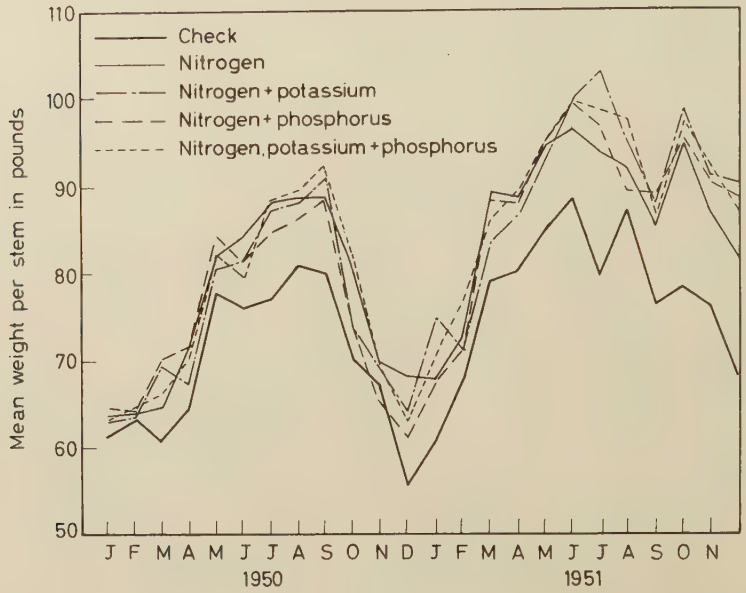

Figure 3. Guaruma NPK *experiments 1950–1; monthly trends of bunch weights*

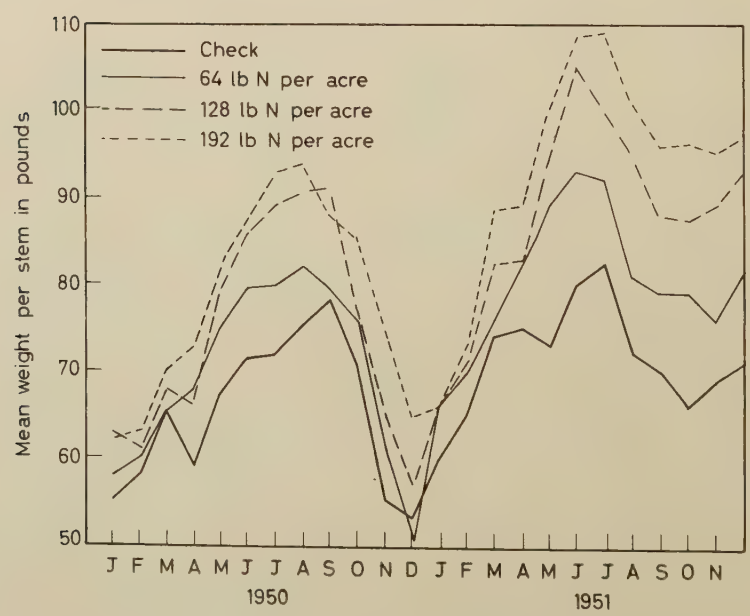

Figure 4. Guaruma nitrogen experiments 1950–1; monthly trends of bunch weights

Figure 5. Gros Michel plant adequately supplied with nitrogen

Figure 6. Gros Michel plant deficient in nitrogen showing the typical 'bunched' leaf bases

Figure 7. Healthy (right) and nitrogen-deficient (left) Gros Michel plants

in conjunction with potassium and phosphorus are included. The differences in potential fertility of the two soil types used in the different tests, are apparent in these data; nevertheless, it will be observed that there has been a steady response to increasing quantities of nitrogen, up to 192 pounds per acre per annum. It is of interest that the Mopala soils, which are obviously capable of producing fruit of excellent quality without any form of fertilizer, have shown substantial increases both in mean weight per bunch and total production per acre following the use of nitrogen.

The differences in mean weight have also been demonstrated in *Figures 1* to *4*, which show mean weight per bunch of fruit, harvested by months, during the years 1950 and 1951. These are of interest mainly in demonstrating an apparent cumulative effect following the use of nitrogen, particularly at the highest level.

DISCUSSION

It is quite obvious from all these data that, on the soil types utilized, the improvement effected by fertilizers is due mainly to nitrogen; neither potassium nor phosphorus has exerted any appreciable influence. In mean weight per bunch, the maximum improvement effected at Guaruma is 12·2 per cent for the nitrogen, potassium and phosphorus combination; the improvement due to nitrogen alone is 11·8 per cent. At Mopala the maximum improvement is 11·0 per cent for the nitrogen–potassium combination; that for nitrogen alone is 9·9 per cent. In these tests the amount of nitrogen utilized was 144 pounds per acre. Potassium varied from 400 to 1 600 pounds per acre of potassium oxide and phosphorus varied from 40 to 640 pounds per acre of phosphorus pentoxide. No differences were apparent for the varying amounts or combinations, either in mean weight or in total production.

In work reported from Jamaica (Dep. Agr. Jamaica, 1950–) on the Lacatan banana, responses to potassium have been obtained and it is becoming clear that deficiency of this mineral is not uncommon in the island. The soils of Jamaica, in comparison with the exceptionally rich alluvia described in the present paper, are infertile and frequent responses to minerals other than nitrogen are to be expected.

The minor elements, manganese, boron, iron and zinc, used in conjunction with a standard application of nitrogen, also exerted little effect upon the weight of the fruit. There was a suggestion of a slightly depressing effect due to boron and manganese, used at the rate of 50 pounds per acre of sodium borate, and 100 pounds per acre of manganese sulphate, but the differences were not particularly significant except during the first ratoon year. However, it is of interest that some depression of fruit weights for these two elements was observed in the earlier Jamaican tests.

It may be of interest to record that no obvious deficiency symptoms were apparent upon banana plants growing in any of these areas, except that of nitrogen, which on Gros Michel is demonstrated by leaves of a paler green colour with reddened petioles and in extreme cases by rosetting of the leaves. In the Mopala plots, none of these symptoms was apparent when the experiments commenced, yet substantial responses were observed after nitrogen applications.

Table 17. Experiments in Honduras, minor element test, January 1950 to December 1951. Chamelecon Valley—Copen plots. Mean weight per bunch. (Full three-quarter grade)

Treatment	Mean weight per bunch in pounds		
	Plant crop 1950	First ratoon 1951	All fruit 1950 and 1951
Check	81·07	110·96	98·74
Manganous sulphate	80·10	109·69	96·97
Sodium borate	80·43	108·85	96·98
Ferrous sulphate	79·93	110·71	98·04
Zinc sulphate	81·55	110·47	98·35
*LSD P 0·05**	1·35	1·98	2·02
0·01	1·78	2·61	2·66

* Least significant difference at 5 per cent and 1 per cent levels.

The actual fruit weights recorded during 1950 and 1951 from an area replanted following flood fallowing are shown in *Table 17*. This test was conducted upon Chamelecon light clay soil. A similar test using all the minor elements in combination as Esminel, a proprietary mixture of the sulphates of copper, iron, managanese, zinc and magnesium with sodium borate added, was repeated on an old ratoonage located on the Mopala soils. A slightly depressing effect was observed here also, following use at the rate of 200 pounds per acre. Although in both cases the differences were small, it is obvious that care should be exercised in utilizing minor elements upon these soil types. Copper was not included in these tests because all areas were under Bordeaux spray for *Cercospora* control and received approximately 300 to 400 pounds of copper sulphate per acre annually from this source. In these minor element tests, as in all others, observations were made regarding possible effects of minor element use upon the activity of the two main plant diseases, *Cercospora* leaf spot and Panama disease. None was apparent.

As stated earlier, this work in Honduras was confined to the two main soil types encountered in this area, both of them alluvial. The use of the demonstration-type experiments, mentioned previously, enabled

intelligent guesses to be made regarding all soil types utilized in the cultivation of bananas in this general area with regard to their probable response to fertilizing. From all of these it was indicated that, for the immediate future, economic response could be expected only from the use of nitrogen.

More recently similar tests, utilizing potassium and phosphorus in conjunction with nitrogen, have been designed in other areas, namely, the Guatemalan, Panamanian and Colombian Divisions of the United Fruit Company. These are still being observed.

SUMMARY

Fertilizer experiments with Gros Michel banana plants in Jamaica over a 13-year period and further studies in Honduras over a 3-year period indicate that economic response to fertilizing can be expected only from the use of nitrogen. Potassium and phosphorus, alone and in combination, in conjunction with nitrogen, produced no statistically significant increase in production over nitrogen used alone. Similarly, the minor elements manganese, boron, iron and zinc produced no significant production increase and, in some cases, exerted a negative effect.

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*A Simple Method for Estimating Oil-mist Deposit on Banana Leaves**

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Low-volume spraying of oil or oil-based fungicides has become increasingly popular for disease control on bananas and other crops during the last few years. An adequate oil deposit uniformly distributed on the leaf surface is required for the spray method.. Failure to obtain good disease control is often caused by faulty spray application. The grower and extension worker need a method to evaluate the coverage obtained on plants sprayed with an oil-mist.

Davis and Elliott (1953) described the use of oil-indicator cards for estimating deposits of oil-based insecticides sprayed by aircraft on forests. The present authors have used this method successfully for studying oil-mist deposits on banana leaves.

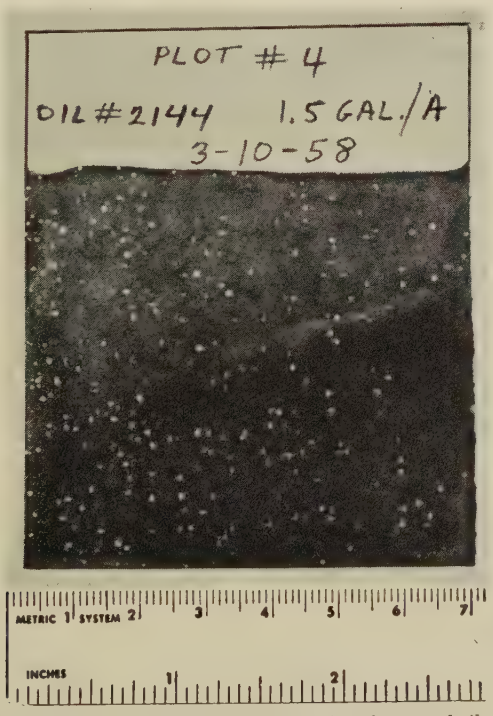

Figure 1. A typical oil-indicator card used to record oil-spray deposit on banana leaves. Note the light marks made by the oil droplets on the dyed portion of the card

* In cooperation with the United Fruit Company, Boston, Mass. and the Esso Research and Engineering Company, Linden, N.J.

MATERIALS AND METHODS

The necessary materials for the oil-indicator cards are: (*1*) an oil-soluble dye, and (*2*) a white, glossy, medium or heavy weight paper with a clay-bearing calender finish. The dye* and paper† recommended by Davis and Elliott were found to work well under tropical conditions. Before coating with dye, the paper is cut into card-size pieces, approximately 2·5 in. × 3·5 in. for convenience of carrying. A saturated solution of dye in acetone is prepared. Each card is dipped into the solution for an instant and allowed to dry quickly. This procedure leaves an adequate coat of dye on the card surface. A 1 in. band along one edge is left uncoated to provide a writing area for labelling.

Oil droplets that strike the dyed surface make permanent, light-coloured spots which can be seen easily (*Figure 1*). The size of the spot is roughly proportional to the original droplet diameter. In the field, the cards are attached to the banana leaves with paper clips. Dew or rain will not obliterate the oil marks on the cards.

Distribution of oil-spray droplets can be observed readily on the cards. The diameters of the droplets also can be estimated. This is done by placing glass slides and oil-indicator cards next to each other on leaves that are to be oil-sprayed with the regular application equipment. After spraying, the diameters of the oil drops on the slides and of the spots on the cards are measured by using a microscope equipped with a micrometer. The average droplet diameter divided by the average spot diameter is the spread factor. For example, in one test using Esso Spray Oil 40, the average diameter of 100 droplets on several slides was 120 microns, and the diameter of 100 spots on the accompanying cards was 505 microns, thereby giving a spread factor of 120/505 or 0·24. Thereafter, when using the same oil, the approximate droplet diameter can be calculated by multiplying the spot diameter by 0·24, the spread factor. A detailed study on sampling droplet size, using these oil-sensitive cards, was made by Thornton and Davis (1956).

DISCUSSION

The cards from each spray application can be placed in a file and kept as a permanent record of spray coverage and relative droplet size. These cards can be used for various purposes such as: (*1*) to compare oil-spray distribution on upper leaf surfaces with that on the lower, (*2*) to evaluate the coverage on young versus old leaves, (*3*) to determine whether poor spray coverage is responsible for occasional cases of no disease control, (*4*) to estimate the overall range of the droplet size. This technique is applicable to almost any oil spray.

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* DuPont Oil Red. Dyes & Chemicals Division, E. I. DuPont Nemours and Co., Wilmington, Delaware.
† Printflex Cover Offset, Process Plate, or Richfold papers. Mead Paper Corp., Chilicothe, Ohio.

Hermetic Sealing of a Stack of Maize with Bituminous Roofing Felt

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Department of Commerce and Industry, Tanganyika

The experiments recorded were carried out to prove the suitability of a cheap readily available covering material for the hermetic storage of stacks of bagged and bulk grain within a conventional warehouse.

The principle followed was that of proved long-term underground pit storage in use in Tanganyika*. It was anticipated that if the covering was reasonably gastight then the respiration of the insects would cause an increase in the carbon dioxide content and a decrease in the oxygen content of the intergranular atmosphere sufficient to kill all the insect life originally present in the stack. A preliminary trial was set up in 1955 in the United Kingdom (Pest Infestation Laboratory, D.S.I.R., Slough, Bucks.) at the instigation of the writer, in which a cocooning layer of plastic was used on a small stack. The success of this trial was reported in *Pest Infestation Research, 1956* (H.M.S.O.) page 20, under the title ' An experimental cocooning of a stack of maize '.

EXPERIMENT I

The maize used was of Tanganyika origin with an initial average moisture content of 10·6 per cent and an initial average temperature of 90°F. There was a live medium infestation of *Tribolium* sp., and a light infestation of *Oryzaephilus* sp. giving an insect count of 24 per two-pound sample. The covering material used was ordinary commercial two-ply bituminous roofing felt which was available in Tanganyika at a price of *E.A. Shs* 35/- per roll of 72 × 3 feet, ex store. The floor of the warehouse which was used was not damp-proofed so a carpet of special dampcourse bituminous felting was laid over the intended site of the stack and the cost of this material was *E.A. Shs* 39/81 per roll of 24 × 3 feet.

The trial extended from 1 December 1956 until 27 November 1957, and the condition of the maize remained unchanged, as reported later in this paper, in November 1958.

Construction and sealing

A 650 ton (approximately) uniformly tight stack of a type which is common in Tanganyika was used. For convenience and economy the length of the stack was 22 feet (shorter than usual) but the normal width of 35 feet and height of 18 bags were used. This involved the building of 1 922 bags, weighing approximately 166 tons, into a stack and approximately 2·5 tons of bulk maize were spread over the top of the stack to form a uniform surface, the bulk maize being retained by a surrounding peripheral line of bags. The vertical sides of the stack were inclined inwards after a height of ten bags

* Swaine, G. (1954). ' The underground storage of maize in Tanganyika.' *E. Afr. agric. J.* **20,** 122.

reducing the width to 22 feet, because it was thought that it might be difficult to apply hot bitumen to vertical joints. In practice, little difficulty was found in sealing the vertical joints with bitumen and the creation of a slope is unnecessary and therefore not recommended because of the consequent loss of storage space.

The uneven floor area on which the stack was built (39 ft × 26 ft) was completely covered with a 2 in. deep layer of sand-soil to reduce possible damage to the dampcourse carpet.

Fourteen rolls of the dampcourse were used to cover the floor area, each roll being laid with an overlap of two inches and sealed to the other with bitumen as an extra precaution against rising damp. A team of six took one and a half hours to complete this work.

The maize was brought in bags a distance of four miles, the building of the stack was completed in four days and the covering of roofing felt completed in twelve working hours. Fourteen rolls of two-ply bituminous felting (72 ft × 3 ft) and one forty-four gallon drum of Caltex B 117 Bitumen which cost *E.A. Shs* 2/15 per gallon, were used.

Figure 1. A prefabricated portion of the end cover being sealed in position. The carpet of dampcourse bituminous felting is seen under the stack

The width plus the height of the stack approximated to the length of a complete roll of felting and consequently this distance from floor to floor over the top of the stack was bridged in one length thereby minimizing the number of overlaps that had to be sealed with bitumen. The vertical overlaps were 8 in. between strips. The length of the strips used on the side of the stacks approximated to fifteen feet and this length included an extra two feet used in sealing the strips to the floor. Three widths of felting, approximately seven feet wide were prefabricated and hoisted into position from the top of the stack as shown in *Figure 1*; the completed sheets being sealed perpendicularly and at the vertex.

The corners were similarly prefabricated and folded envelope fashion (*Figure 2*) being bitumen sealed as laid.

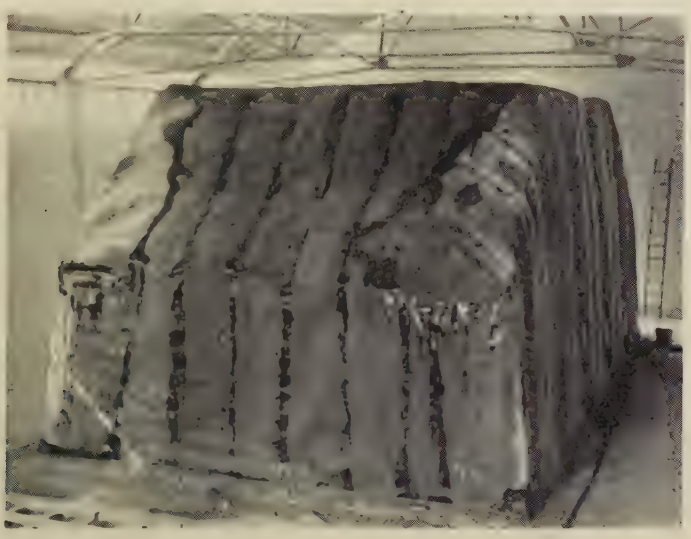

Figure 2. The completed cover

The operation was completed by bituminizing all ends at floor level (*Figure 2*) at right angles to the overlapping dampcourse.

Six artisans working under part-time supervision carried out the operation and no difficulties were encountered in securing an adequate seal although a certain amount of bitumen was inadvertently wasted when sealing the vertical joins. Two lengths of tubing were inserted a distance of one foot into the stack to enable samples of the air to be taken. Each tube consisted of a length of $\frac{1}{4}$ in. rubber tubing, one length inserted into the stack at each end in the vertical mid-line, at heights of four and eleven feet from the bottom of the stack, and to each of these a length of lead-off tubing was added and a screw-clip was fitted.

Results

The efficiency of the sealing was determined by withdrawing samples of the contained air through the sampling tubes, the oxygen and carbon

dioxide concentrations being measured by normal laboratory methods. Alkaline pyrogallol was used to absorb the oxygen and sodium hydroxide to absorb the carbon dioxide. The average oxygen and carbon dioxide concentrations present at different periods of the storage trial are shown in *Figures 3* and *4*.

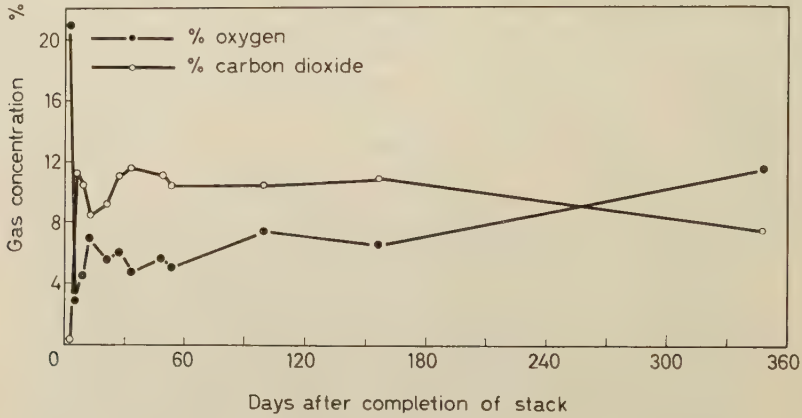

Figure 3. Percentages of oxygen and carbon dioxide present in intergranular atmosphere of stack used in Experiment I

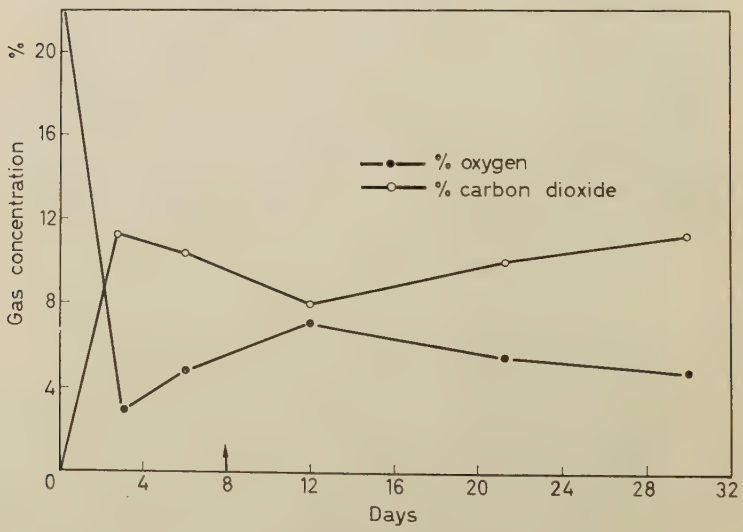

Figure 4. Experiment I. Intergranular atmosphere. Arrow indicates date of accidental damage to stack

During the first four days there was a rise in the concentration of carbon dioxide to a maximum of 11·5 per cent and a decrease in oxygen concentration to a value of 3·3 per cent. After seven days the carbon dioxide concentration was 10·6 per cent and the oxygen value had risen to 4·3 per cent. On the eighth day the stack was accidentally pierced on one side about six feet above floor level by workmen working on a nearby stack and it was

not possible for patching to be effected for 24 hours; this possibly contributed to the concentration of 8·2 per cent carbon dioxide and 7·1 per cent oxygen on the thirteenth day.

On the eighteenth day the felting was seen to have further damage, a hole one inch in diameter pierced in the top by a thin stick three feet long. The end of the stick appeared to have been trodden through the felting; although blocking the hole it did not seal it and live *Tribolium* sp. were found on the stick and in the near vicinity in small numbers. Sealing was effected immediately but little information could be obtained as to when the damage had been done. Photographs taken on the day the cover was completed gave inconclusive evidence of the stick being in position at that time. This may well have been a part answer to the slight leak indicated by the variations in the concentration during the fourth to seventh day period and the continued drop in carbon dioxide and rise in oxygen concentrations registered over the following six-day period.

Test samples taken some three days after the leak had been sealed showed that the carbon dioxide concentration had increased by 0·9 per cent to 9·1 per cent and that the oxygen concentration had dropped by 1·4 per cent to 5·7 per cent. On the thirty first day after sealing this recovery was further evident, the concentrations being 11·4 per cent carbon dioxide and 4·8 per cent oxygen, concentrations of these gases which would be expected to arrest insect development. On the fifty second day these gas concentrations showed little variation as reference to *Figure 3* indicates and it was decided to take samples of the maize. On the fifty sixth day three twelve-inch square apertures were cut in the roofing felt and samples taken. An insect count showed ten live insects (five *Tribolium* sp. and five *Oryzaephilus* sp.) in a two-pound sample, representing a 50 per cent kill in 56 days. The maize was bright, clean and sweet. The apertures were resealed immediately after the sampling, each operation taking no longer than three or four minutes.

As the trial was intended to provide information for the long-term storage of grain, provided the results of the analysis of the enclosed atmosphere were satisfactory, it was decided not to open this stack for a considerable period. Analyses determined on the ninety eighth and one hundred and sixtieth days gave satisfactory concentration values and the stack was allowed to remain untouched until the three hundred and forty seventh day when the oxygen concentration was found to have risen to 11·6 per cent and the carbon dioxide concentration had fallen to 7·7 per cent. It was decided to sample the grain again and this sampling took place on the three hundred and sixtieth day. No live infestation of any kind was found. There was a fairly strong smell of carbon dioxide and three samples from eight gave off a slightly musty odour. These samples which were taken from identifiable bags and which represented about 10 per cent of the total bulk, had initially been of very poor quality and of slightly more than medium infestation when built into the stack. The smell tended to disappear after exposure to the atmosphere and the maize was considered to be fit for milling, proving to be palatable after treatment for the removal of insect damage.

The rest of the stack, consisting of the major portion which was originally both of better quality and lighter infestation when placed in the stack, was

also found to be completely free of live infestation and in a first-class condition, cool, sweet and of very similar condition to maize of the same quality now successfully stored in the Territory's underground pits for over three years.

After exhaustive sampling the stack was resealed for permanent storage as part of the Territory's reserve. Following the successful experiment, a full-sized stack of the normal length of approximately 72 ft was constructed in December 1957, and the contents of this, together with those of the experimental stack described in this article, continue to remain in the described unchanged conditions.

The oxygen and carbon dioxide concentrations inside both of the stacks on the day of construction were assumed to be the same as the normal atmosphere in Dar-es-Salaam.

EXPERIMENT II

A large stack of 594 tons of medium infested bagged maize was enclosed in bituminous felting in a similar fashion to that described in experiment I, the work being completed on 12 March 1958. The work was carried out by the Staff of the Department of Commerce and Industry and the cost was *E.A.Shs* 11/22 per ton, this amount including the cost of additional labour employed, but excluding the salaries of permanent staff of one Asian and one African assistant and the supervisory work of the author.

The average gas concentrations obtained in this stack are illustrated in *Figure 5* and indicate a steadier trend than that obtained in experiment I.

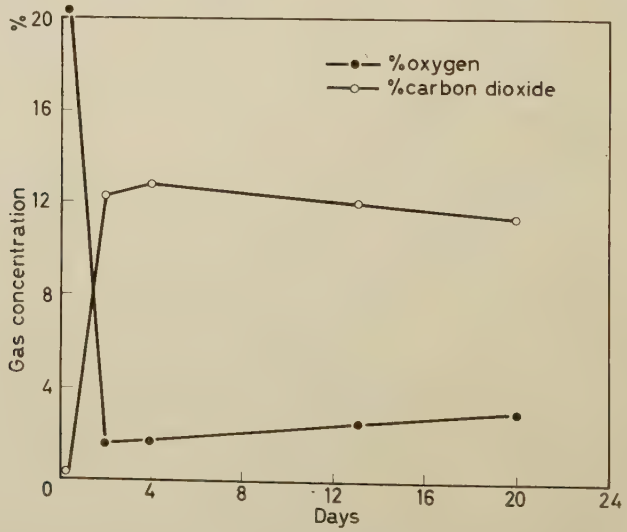

Figure 5. Experiment II. Intergranular atmosphere

DISCUSSION

Hermetic sealing of stacks of bagged grain stored in a normal warehouse can be achieved by the use of a reasonably priced roofing felt, this being strong enough to retain a stack of maize in good condition for at least two

years. If the cover suffers damage, it can be repaired easily and cheaply with patches. Experience gained in Tanganyika of hermetic storage of grain below the ground, the principle being the same, suggests that there would appear to be no reason why the good condition of the grain should not be retained indefinitely with the storage method now reported. Lopez reports that wheat has been successfully stored in Argentina in underground pits for thirteen years. Tanganyika's experience of pit storage covers three years with the grain remaining in as good a condition as when it was put into store.

The bituminous felt covering is sufficiently vapour-proof to enable higher concentrations of carbon dioxide and lower concentrations of oxygen than are present in the atmosphere to be created and maintained (*Figure 3*), the latter value apparently being reduced low enough by the respiration of insects to cause their death. In this trial it is of interest to note that the oxygen concentration did not fall below 3·3 per cent and control was apparently effective even with 7·2 per cent oxygen present.

No change in moisture content took place in the maize and therefore the cover can be assumed to be reasonably water vapour-proof.

The 166 ton stack was exposed to a number of possible sources of re-infestation (20 feet away) and the walls of the godown were 10 feet away at the nearest point. During the first eight months *Ephestia cautella* from adjacent stacks were frequently seen to alight and remain on the cover; *Tribolium castaneum* settled in fair numbers on the crevices of the bitumen seal. After this period the nearby stacks were removed and the cover sprayed with contact insecticide, with the result that gradually all the insects died. No live infestation of any kind was found in the stack, thus the cover can be considered to be reasonably resistant to insect penetration and consequently to re-infestation from outside sources.

The stack cover was attacked and successfully penetrated by rodents at one place at floor level in the eleventh month, between examination on the three hundred and forty seventh day and sampling on the three hundred and sixtieth day. This suggests that it would be better to protect the bottom of the stack by at least one additional strip of felting, preferably three-ply material six inches wide, running round the base of the stack.

The roofing felt had not suffered any deterioration beyond an accumulation of dust and, carefully removed from the stack, the roofing felt should be re-usable. The company which manufactured the felting advised that under the conditions of this experiment, no deterioration at all should take place in their product.

The cost of such covers in Tanganyika would appear to be of the order of not more than *E.A.Shs* 7/50 per ton of produce stored, plus labour charges of a similar amount if a servicing company is employed. Using staff trained in the handling of these materials it should be possible to reduce these latter charges considerably.

Non-standard weight bags were used for the trials and this resulted in certain stacking difficulties. For ease of working only standard size bags should be used. In experiment I, corrected in experiment II, stacks were not allowed to settle before covering and this resulted in a slight sagging of the walls of the covering material which, however, did not prove to be a

real disadvantage. It is recommended, however, that at least one month should be allowed for settling before an attempt is made to lay the cover.

In connection with this subject, it is also pertinent to report that 1 624 tons of maize were sealed in pits at Moshi during March 1958 and the cost using the same staff as mentioned earlier in this report and excluding their salaries but including all labour employed, materials, transport, etc. was *E.A.Shs* 7/21 per ton, the lowest amount so far attained by the Department in covering pits.

ACKNOWLEDGEMENTS

Thanks are due to the Director and Staff of the former Grain Storage Department of the Tanganyika Government for making the experiment possible, to Messrs Naumann Gepp and Co. Ltd for the roofing felt workmanship and to the Tanganyika Government Chemist and his staff for gas sampling and concentration determinations. Particular assistance was rendered by Mr E. V. R. Khomo of this latter department, and his interest and knowledge were very much appreciated.

The help and assistance of the Pest Infestation Laboratory, Department of Scientific and Industrial Research, in the compilation of this paper is also gratefully acknowledged, particularly in the preparation of *Figures 3*, *4* and *5*, which are Crown Copyright.

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Conservation and Utilization of Stylosanthes gracilis

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Although *Stylosanthes gracilis*, commonly known as 'Brazilian lucerne', was introduced into the Federation of Nigeria in 1947 from Queensland, Australia, little work has been carried out on its utilization as livestock feed. In the Eastern Region of Nigeria more emphasis has been laid on its use as a green manure crop and as a soil cover and less on its value as a source of livestock feed of high protein content. Perhaps this is understandable as the soil type on which this legume crop was established varied from deep leached and erodable sandy soils to shallow ironstone soils in the drier areas of the Region.

Among its very desirable agronomic characteristics are the ease of establishment from seed and suitable stem cuttings even on poor sandy soils; its quick colonizing habit to the virtual exclusion of weeds; and its deep and extensive root system which, by exploiting the soil's moisture, enables it to remain green throughout prolonged dry seasons in which other cover and forage crops have withered away.

The effect of seasonality of production of pasture herbage on livestock growth and production is well known. The nomadic Fulani herdsmen in Northern Nigeria migrate during the dry season in search of pasturage for their cattle. In the Eastern Region goats and sheep browse and depend on evergreen shrubs for most of their keep in the dry season when every pasture crop of value has either withered away or become too stemmy to be of use as a feed. Lansbury (1958) quotes unpublished work at the University College of Ghana in which dry season wasting of cattle caused by shortage of grazing was found to be quite substantial even in a mild dry season. In order to mitigate dry season loss in weight, he suggested feeding of rice straw to West African cattle in rice growing areas.

At best rice straw can only be regarded as poor quality energy feed, the production of which is at present localized in the swamp areas of the Region. Furthermore, in most of the Eastern Region farms there is practically no crop residue (especially those of legume origin) which may be utilized in feeding livestock.

Fortunately *Stylosanthes gracilis* grows readily throughout the Region. Through its dual role of improving and conserving the soil and as a source of protein-rich fodder, it will undoubtedly meet the need for a source of reasonably cheap dry season concentrate for feeding livestock. It is with this object in view that the trial described below in conservation and utilization of this legume crop was initiated. The cost of producing this home-grown protein feed is compared with farm landed prices of purchased protein foods of plant origin, as cheapness of production is definitely a

pivotal factor in deciding whether or not livestock on a farm will be maintained on locally grown or purchased protein feeds.

ESTABLISHING AND CONSERVING THE CROP

During the early rains of 1958, one acre of land was seeded down to *Stylosanthes gracilis* by broadcasting on a sedimentary red sandy-loam ironstone soil at Nkwelle Agricultural Station. The soil was ploughed and harrowed once before seeding. Superphosphate was applied at the rate of 1·5 cwt per acre. During the establishment period (the ensuing wet season), the crop was weeded only twice after which it made such excellent growth that it was able to suppress competing weeds.

By December 1958, six months after seeding, the sward had attained an average height of 3 ft and for all practical purposes was a 100 per cent stand and suitable for cutting and feeding to livestock. It was decided to conserve half of the crop and leave the remainder for seed harvest in the late dry season as previous observation on a seed plot of *Stylosanthes* had revealed that the crop comes into flower in January and matures its seed by March of the same year.

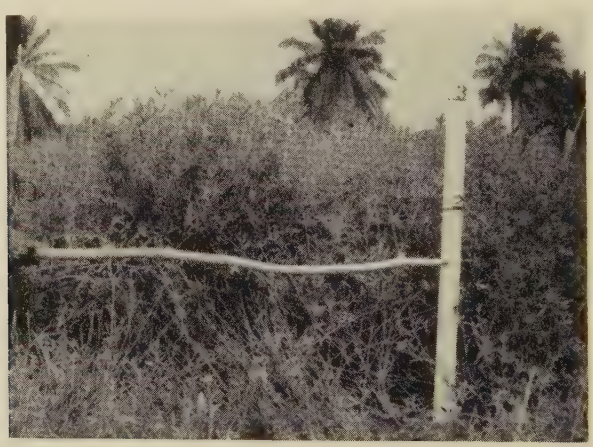

Figure 1. Standing crop of Stylo, showing cutting height of 18 in.

As no previous knowledge existed, at least in this part of the country, on the optimal cutting height of Stylo, it was decided to cut at a height of 18 in. Above this height, it was observed that the sward consisted largely of leafy and succulent shoots while below were to be found woody stems and branches of low nutritional value (*Figure 1*) which were left as long stubble after cutting.

The harvested forage was cured as hay over a period of seven days on rows of wooden trestles which provided broken tunnels of freely circulating air for ventilation under each stack (*Figure 2*). On the eighth day, after the hay was properly cured, it was hammer-milled (*Figure 3*) and bagged for storing over the dry season.

Throughout the period from the time the crop was harvested till milling and bagging were completed the weather was cloudy to bright and no

rain fell. Loss of the brittle leaves as a result of shattering was at a minimum since handling was cut down to what was absolutely necessary. On the whole the resulting Stylo meal was of the highest possible quality consistent with the stage and condition of the crop, careful operations and prevailing weather conditions throughout the period.

Figure 2. Stylo hay drying in field on wooden trestles

Figure 3. Hammer-milling Stylo hay

RESULTS

Table 1 gives an idea of the order of yield, at first cut, of *Stylosanthes gracilis* grown on this type of soil. In round figures one may expect 3 ton/acre of forage equivalent to 1·5 tons of hay or 1 ton of Stylo meal. In *Table 2* is presented the chemical analysis of the meal. It is seen to be a very rich source of calcium, good in protein and fairly good in phosphorus. The meal retained a yellowish-green colour, indicating that much of its carotene (precursor of vitamin A) was not lost during hay-making, and would thus be a useful source of this vitamin. Thus it compares very favourably with

temperate lucerne or alfalfa as a source of nutrients for productive farm animals.

The small flock of sheep on the farm were largely maintained throughout the protracted dry season on a ration of Stylo meal supplemented with Bambara Dusa, the by-product of *Voandzeia subterranea* nuts obtained after crushing and sieving the nuts in a plate mill.

Table 1. Yield of green forage, hay and milled product from a plot of non-flowering six-month-old crop of Stylosanthes gracilis

Strip	*Acreage*	*Wt of green forage, lb*	*Wt of cured hay, lb*	*Wt of milled product, lb*
1	0·11	794·0	374·0	257·0
2	0·09	810·0	469·0	243·5
3	0·11	540·0	372·0	223·0
4	0·13	724·0	388·0	318·0
Total	0·44	2868·0	1603·0	1041·5
Yield/acre		6518·2	3643·2	2367·0

Table 2. Composition of Stylosanthes hay cut before flowering (as per cent dry matter)

	Stylosanthes	*Lucerne (after Halnan, 1949)*
Moisture	14·91	10·7
Silica free ash	8·88	8·4
Protein	17·57	14·6
Fat	2·59	1·8
Fibre	28·91	31·0
Soluble carbohydrate	44·36	33·5
Calcium (CaO)	4·30	2·52
Phosphorus (P_2O_5)	0·65	0·65

UTILIZATION

Stylosanthes gracilis may be cut green for soiling to all classes of livestock especially in the rainy season when weather conditions are unfavourable for hay-making. It is necessary to wilt the herbage before feeding in order to remove the disagreeableness of the harsh hairs which possibly make livestock graze a standing crop only sparingly.

Reference has been made above to the drought-resisting quality of the crop which enables it to carry a luxuriant growth of leaves well into the dry season without running quickly to seed. Under our conditions the crop initiates flowering in January, and by mid-February it is in full bloom at which stage it could be cut and fed or conserved. Thus from the point of view of farm management *Stylosanthes gracilis* fits admirably into the scheme of things. The conservation of the crop can, with advantage, be delayed and carried out during the dry season slack period without serious detriment to the quality of the product.

It was found more convenient to conserve the crop as hay rather than as silage in view of the smallness of the crop, and in view also of seepage and spoilage losses which inevitably occur when succulent legume forages are ensiled in pits. If good quality is to be had, it is essential to handle the

crop as little as possible in order to minimize losses due to shattering of leaves. Of even greater importance are losses in a hay-stack which result ultimately in poor quality hay.

Milling the hay and storing in sacks eliminates these losses and makes better storage possible. It also makes a more efficient utilization possible by cutting down the amount of wastage during consumption and by facilitating strict rationing.

Chemical analysis has shown it to be an excellent source of protein and minerals. It can thus be conveniently fed to ruminants (cattle, goats and sheep) as concentrated feed especially in the dry season when grazing is short. If the meal is not too fibrous it can, with advantage, be included in rations for poultry and pigs.

It is possible to make a less fibrous meal by cutting the crop at a younger stage. Although the resulting meal would be of a higher nutritive value, the yield of hay would also be smaller thus making the cost of production higher. We do not as yet know the optimum stage at which to harvest the crop in order to get the best of both worlds. By constantly removing woody stems from the hay during milling, it is possible to produce a meal which will suit the digestive systems of non-ruminants. This practice is strongly recommended as a routine during milling.

We cannot ignore the cost of producing the meal. Its use in stock feeding will be limited if it should prove too expensive to produce. Fortunately the

Table 3. Cost of growing and milling Stylosanthes gracilis

Establishment costs	*Man-days/ac.*	£	*s*	*d*
Clearing low bush	10	2	1	8
Cultivations (mechanical)	—	1	7	9
Sowing seed in drills at 5 lb/acre	4	—	16	8
Hand weeding (twice)	32	6	13	4
Fertilizer: 1·5 cwt superphosphate/acre		1	19	0
Labour for application	1	—	4	2
Collecting and threshing 5 lb seed	10	2	1	8
Total	57	15	4	3
Life of ley 3 years				
Establishment cost/acre/year	£5 1*s* 5*d*			
Est. cost per cut (three cuts/year)		1	13	10
Rent		—	10	0
Handcutting and stacking (11 man-days)		2	5	10
Total field cost per acre		4	9	8
Yield of meal/acre 1·1 ton				
∴ Field cost/ton of meal		4	1	6
Milling cost/ton		9	3	4
Total cost of 1 ton of Stylo meal		13	4	10

Table 4. Unit value of protein from different sources

Feed	*Approx. cost per ton, £*	*Cost/100 lb, pence*	*Digestible protein, %*	*Cost/lb D.C.P., pence*
Groundnut cake	£29 2 0	311·8	40·0	7·8
Palm kernel meal	£23 12 0	252·9	17·4	14·5
Stylo meal	£13 4 10	141·9	17·6	8·1

cost of production is not prohibitive. *Tables 3* and *4* set out the costs involved. Although the crop can stay down as long as six years without marked deterioration, the life of the present crop is fixed at three years because after this period it will be ploughed up for arable cropping.

In *Table 4* the unit cost of protein in Stylo meal has been compared with that of purchased protein from plant sources. Groundnut cake and palm kernel meal are the two commonly used purchased concentrate feeds. It is seen from *Table 4* that the protein in groundnut cake is about as cheap as the protein in Stylo meal and both are considerably cheaper than the protein in palm kernel meal. By judicious use of fertilizers and care in establishment and milling, it is possible to reduce the production cost of Stylo meal. There is no reason therefore why this forage crop should not find a more extended use in the feeding of livestock than is the case at the moment. Combined with its use as a green manure crop and a soil cover, it should play a greater role in livestock feeding especially during the dry season.

We need to learn more about the management of the crop. At the moment it is advisable to cut it with caution and take not more than three cuts in the year, the last being taken during the late rains to facilitate seed collection in late dry season.

Because of the procumbent nature of the main stem and branches, the crop is particularly liable to damage by trampling which kills the tender branches and causes splitting of basal branches from the parent stem.

SUMMARY

The conservation and utilization of *Stylosanthes gracilis* is described. At the moment its potentiality as a forage legume is little exploited. By conversion to a meal, it is possible to produce a concentrated feed which compares favourably in food value with temperate lucerne. A pilot trial has indicated that the cost of producing the meal is sufficiently cheap to warrant a more extended use of this material in dry season feeding of livestock.

ACKNOWLEDGEMENT

The writer acknowledges with thanks the assistance of Dr V. A. Oyenuga of University College, Ibadan, for carrying out the chemical analyses of samples of the Stylo meal.

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Some Climatological Observations on Amelonado Cacao

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West African Cocoa Research Institute, Tafo, Ghana

Extreme variability in the growing conditions of cacao in Ghana, even that small fraction grown on a plantation basis, results in marked differences in habit, vigour and yield, even between neighbouring trees. Accordingly, experimental plots must receive generous replication, and the accumulation of pretreatment data may be necessary for field trials to yield the information required (Cunningham, 1959). One way of reducing this lack of uniformity could be through a better understanding of the relative importance of different ecological factors, but this approach has been largely neglected. Agronomic trials (W.A.C.R.I., 1950–57) have been concerned with the effects on vigour and yield of a variety of treatments, such as spacing of trees and type of shade, and a comparison of Amelonado cacao with more recently introduced Upper Amazon varieties; but records to assess the precise effects of the experimental treatments on the ecology of the crop were not made.

Similarly, environmental changes caused by removing virus-infected trees, during routine operations for the control of Swollen Shoot disease, have not been critically examined; nor have the ecological conditions to which young cacao seedlings are subjected during attempted re-establishment in devastated areas, which all too frequently fails. During entomological studies it has been shown that cacao trees exposed to direct sunlight are more prone to attack by cacao Miridae than those under shade (Williams, 1953), and that breezes, which may transport the mealybug vectors of cacao viruses, are stronger near ground level under a continuous cacao canopy than in or above it (Cornwell, in press). Again, the precise effects of environmental conditions on these pests have not been adequately studied†. Meteorological data have been recorded from an exposed site in a Stevenson's screen at the West African Cocoa Research Institute for 20 years, but these are of limited value in assessing the diurnal and seasonal changes that occur within the crop itself.

In the present study, two factors contributing to the microclimate within cacao have received some attention: temperature changes in a Stevenson's screen outside cacao and those within peasant cacao, at ground level and in the upper canopy, are compared; so too are changes in evaporation rate at different elevations in Amelonado cacao with a continuous canopy, and in a small clearing resulting from the removal of virus-infected trees.

TEMPERATURE CHANGES

Maximum, minimum and 9.0 a.m. temperatures were measured in the screen with mercury-in-glass thermometers on 40 days during July and

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† Mr A. Wharton, at the West African Cocoa Research Institute, has made some meteorological records in the course of work on Black Pod (*Phytophthora palmivora* Butl.), but these are as yet unpublished.

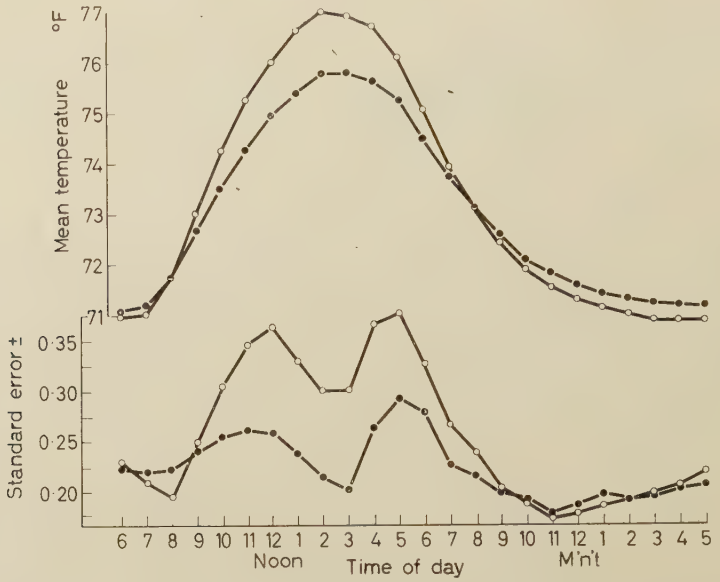

Figure 1. Diurnal changes in the mean of temperatures recorded in farmers' cacao at ground level (closed circles) and at the top of the canopy (open circles) on 40 days during July and August 1955. Changes in the standard error of the means indicate the magnitude of day to day variations in temperature at different times of the day

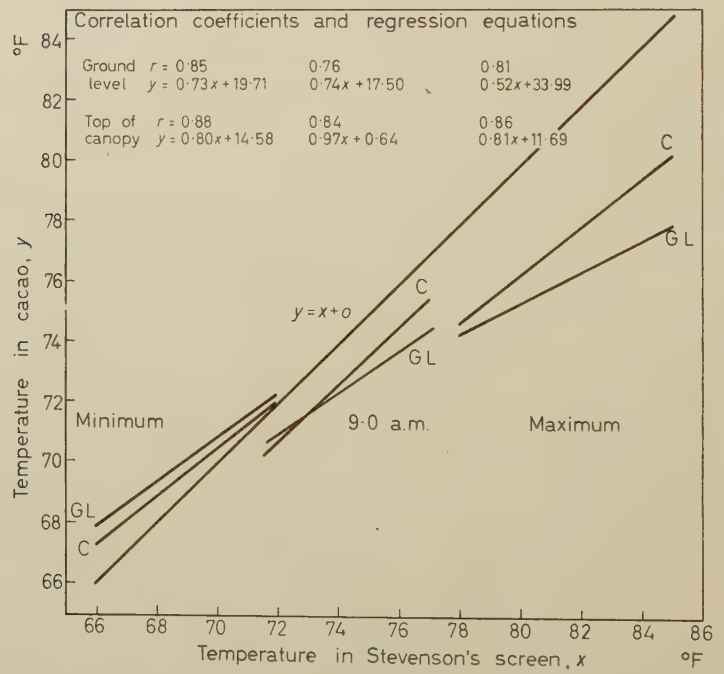

Figure 2. Relationships between the minimum, 9.0 a.m. and maximum temperatures recorded in a Stevenson's screen outside cacao and the corresponding values obtained in farmers' cacao, at ground level (GL) and at the top of the canopy (C). Measurements taken on 40 days during July and August 1955

Figure 3. Changing the positions of atmometers after recording the amount of water evaporated at four levels above ground, in a clearing caused by the removal of virus-infected cacao

August 1955. Corresponding shade temperatures in mature farmers' cacao half a mile from the screen were measured with Cambridge continuous recording thermometers, at ground level and 19 ft above ground in the upper levels of the canopy.

In cacao, minimum and maximum temperatures occur between 3 and 6 a.m. and between 2 and 3 p.m., respectively (local time). Temperatures in the upper canopy exceed those at ground level between 9 a.m. and 7 p.m.; during the hours of darkness, temperatures in the canopy may fall below those at ground level by about 0·3°F (*Figure 1*). Changes in the standard error of mean temperatures reflect the magnitude of day to day variations. These are more marked in the canopy than at ground level, and are considerably greater when the temperature is increasing (10 a.m. to 1 p.m.) or decreasing (4 to 6 p.m.) than when it is maximal or minimal. Clearly, below a closed canopy, temperatures are buffered against diurnal and day to day fluctuations, indicating the existence of a more stable environment than obtains in the canopy itself.

Further evidence of thermal insulation is obtained when the daily minimum, 9 a.m. and maximum temperatures in cacao are correlated with the corresponding values recorded in the screen (*Figure 2*). At a screen minimum

of 66°F, the temperature at ground level exceeds that in the canopy by 0·6°F, and the screen value by 1·9°F. At a screen maximum of 85°F, the ground-level temperature in cacao is lower than the canopy reading by 2·4°F, the latter being 4·7°F below that obtained in the screen. Thus, temperatures at canopy level are also buffered, though to a lesser degree than those below, against the wide diurnal range experienced outside the crop. In peasant cacao, this insulation is provided by the shade cover of indigenous forest trees.

CHANGES IN EVAPORATION RATES

Changes in evaporation rate were measured using white Livingstone atmometer bulbs fitted to Winchester quart bottles. Small mercury non-return valves prevented the bottles from refilling during heavy dew and rain. Rates of evaporation were measured at four elevations—1·5, 12, 21 and 30 ft above ground—in cacao with a closed canopy between 15 and 25 ft, and at the same levels in a clearing about 10 yards across, where trees with symptoms of Swollen Shoot disease had been removed. At these two sites, which were 25 yards apart, wooden towers were constructed to support the four atmometers (*Figure 3*), which operated near the ground, in the middle of the canopy, and a few feet above and below it.

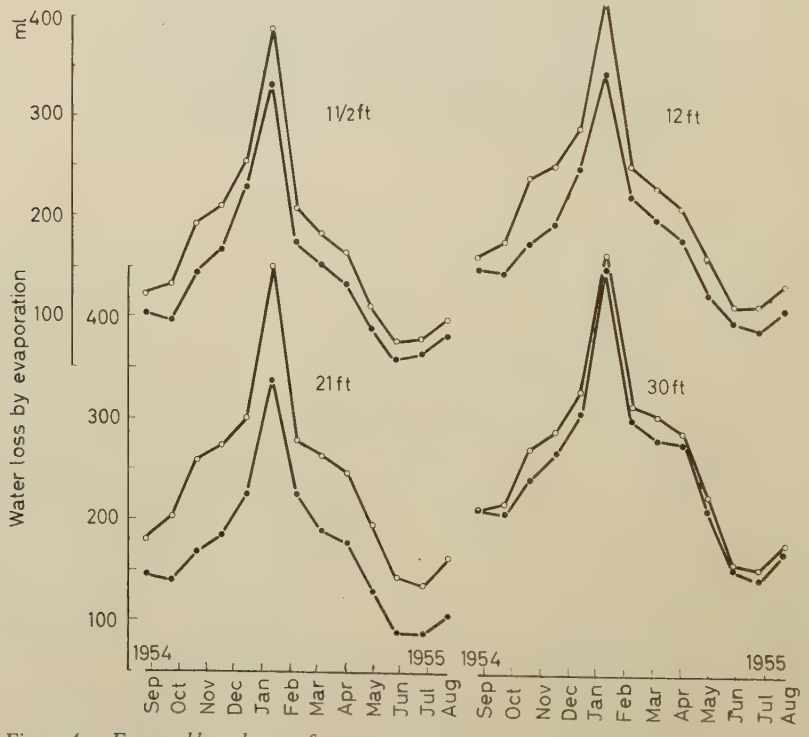

Figure 4. Four-weekly volumes of water evaporated from Livingstone atmometers at four heights above ground, in cacao with a continuous canopy (closed circles) and in a small clearing from which virus-infected trees had been removed (open circles)

The atmometers were first calibrated under uniform conditions, no attempt being made to equate water loss with absolute measurements of saturation deficiency. They were installed on 10 September 1954, and measurements of evaporation were made at weekly intervals until 9 September 1955. At refilling, the bulbs were swabbed with damp cotton-wool to remove algal growth. The position of each atmometer was changed weekly; those at ground level were moved to the tops of their respective towers and the others downwards, to the next level. By this means slight differences in performance were eliminated.

Changes in evaporation rate throughout the year are shown by measurements of water loss summed over four-weekly periods (*Figure 4*). Water loss in the clearing exceeded that in standing cacao at all elevations—by 21·0 per cent near the ground, 21·1 per cent just below the canopy, 40·6 per cent at canopy level and 5·0 per cent above it. Evaporation rate in the clearing increased linearly with height, but among standing trees the canopy reduced evaporation considerably; within it, less water was lost than just below, though more than near ground level. Seasonal changes in evaporation rate were marked at both sites. The ratio of minimum to maximum values in the clearing decreased with elevation from 4·9 just above ground to 3·6 just below the canopy, 3·3 level with it, and 3·0 above it; in standing cacao corresponding values were 5·5, 3·8, 3·8 and 3·1. Thus, the seasonal range is greatest at ground level and diminishes with height, and the greater rate of evaporation where trees have been cut out is associated with a smaller seasonal variation.

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Book Reviews

REPORT ON THE 1950 WORLD CENSUS OF AGRICULTURE
Vol. II: Census Methodology

United Nations Food and Agriculture Organization: Rome, 1958.
ix + 168 *pp.* 10*s*

Volume I of this report gives the Census Results by Countries and is gradually being published in loose-leaf form. The second volume provides an analysis of the questionnaires and the associated instructions which were prepared for the various national censuses. A third volume, completing the report, will comprise an analysis of the main subjects included in the census.

Census Methodology (Vol. II) opens with the historical development of the world census idea, from an attempt in 1870 to prepare existing statistical information in comparable form (International Statistical Conference at the Hague) to the coordination of national censuses, first in 1930 and then in 1950. A programme for a decennial World Census in 1940 was drawn up but World War II prevented its accomplishment.

In describing the scope of the programme proposed by the F.A.O. in Chapter 2, attention is drawn to the change in emphasis in the world censuses from agricultural production to ' information on the number of agricultural holdings, and their principal characteristics '. This chapter also includes a comparison of the short and expanded lists of items. The following chapter analyses, section by section, the participation and conformity of each national census with the F.A.O. programme. This information is presented mainly in tabular form with footnotes indicating the departures from the coverage or concepts of the individual questions.

A useful final chapter deals with the main definitions and concepts. For each census schedule—from section A: Holder & Tenure to section K: Wood & Fishery Products—the main features of the concepts incorporated in the F.A.O. programme are given first and then the concepts employed in the national censuses are reviewed.

First impressions might suggest that this substantial report is one mainly of historical interest. But it is on the experience of the past that future plans are laid, and so for those concerned with agricultural statistics, whether national or international, much of value can be gained from this volume. For example, the discussion of definitions, concepts and coverage of the various questions will be helpful not only to those who have to plan future censuses—in particular, the 1960 World Census of Agriculture—and to provide appropriate instructions, but also to those concerned with the accurate interpretation of agricultural statistics and problems of comparability and uniformity.—G.E.H.

TABULATED INFORMATION ON TROPICAL AND SUBTROPICAL GRAIN LEGUMES

United Nations Food and Agriculture Organization: Rome, 1959.

xiii + 367 *pp.* 17*s* 6*d*

This publication has an aptly descriptive title. It is part of the F.A.O.'s long term project of coordinating research into tropical and subtropical pulses, or grain legumes, with a view to the eventual improvement of the widely spread protein-deficient diets in those areas. This preliminary stage tabulates answers to a questionnaire—in questionnaire page form—returned by 27 territories (notable exceptions being Malaya, Indonesia and the Philippines), covering 360 cultivars within 38 species. Nomenclature has been checked at Kew and a useful list of synonyms included in the work.

The reviewer found that the most valuable part of the document was the Appendix. This describes the geographical location, temperature, precipitation and soil type of the stations submitting replies—a further notable omission, however, being data on length of day, which, in relation to crop agronomy, should be included in all physiographic descriptions. Temperature data are meagre, being confined to mean annual minima and maxima, and therefore giving little indication of the monthly distribution. The key to the tabulated information is also useful in showing the geographic range and relative importance, in terms of numbers of cultivars, of the species dealt with; the first four of these being *Phaseolus vulgaris* 66, *Arachis hypogaea* 43, *Vigna sinensis* 32, and *Glycine max* 25.

The questionnaire was undoubtedly designed so that breeders and agronomists might select at a glance possible cultivars of use to their particular programme. It is disappointing, however, to find that replies to just those items such as susceptibility to pest and disease, which would be of use to the plant breeder, have largely been omitted. In fact the average response to the fifty odd questions called for per entry is little more than fifty per cent. In addition, the majority of replies are of necessity rather bald, dogmatic and unqualified single statements that give the reader little workable information on the true value of the crop. It is doubtful therefore whether the ' tabulated ' approach to securing this type of information is justified. Of greater value would be the ' Annotated Bibliography ' based on published papers, including sections in Departmental Annual Reports, and in this respect the F.A.O.'s *Legumes in Agriculture* is by far the more informative and interesting publication on this subject.—R.H.F.

MEMÓRIAS DA JUNTA DE INVESTIGAÇÕES DO ULTRAMAR

(1) São Tomé e Príncipe e a Cultura do Café

Hélder Lains e Silva. *xii* + 499 *pp.* (illus.) Lisbon, 1958

(2) A Agricultura do Arquipelago de Cabo Verde

A. J. da Silva Teixeira and L. A. Grandvaux Barbosa. 178 *pp.* (illus.) Lisbon, 1958

These two books reflect credit on Portuguese agricultural science. In the first, the author is concerned to survey the possibilities for rehabilitation and

extension of the coffee industry in São Tomé and Príncipe. Employing modern conceptions of land-use planning, he incidentally tells us much about the general environment for agriculture in these islands. There is an English summary of 34 pages.

The second volume in this series deals with the general agricultural problems of the Cape Verde Islands. Few tropical environments can be as harsh for the farmer, and indeed the casual ship passenger to St Vincent may be forgiven for supposing that it never rains there. The authors naturally recommend increased irrigation, do not give a high priority to cotton whose possibilities they were commissioned to look into, think that sugar-cane should be decreased and pastures improved. The English summary is of 4 pages.

Both books are lavishly illustrated with maps and photographs.—G.B.M.

PLANNING OF EXPERIMENTS

D. R. Cox. Wiley: New York; Chapman and Hall: London, 1958. *vii* + 308 *pp.* (illus.) $7.50 or 60*s*

The planning of an experiment or an experimental programme is always important, whether in agricultural or some other branch of experimental science. Within recent years, increasing attention has been given to this aspect of experimentation and this book presents an admirable account—comprehensive and thorough, yet free from statistical and mathematical technicalities—of the basic statistical ideas underlying modern experimental design. Extensive use has been made of examples drawn from various branches of experimental science. Dr Cox is concerned to give an appreciation of the nature of the various types of designs which are available and their likely uses rather than instruction in methods of construction or details of analysis. In consequence, the analysis of variance, for example, only receives incidental mention. Considerable attention is also given to other important topics involving statistical considerations such as the choice of experimental units, treatments, levels and observations, which are not fully discussed elsewhere. The book is thus a most valuable complementary volume to the existing standard texts on design and analysis of experiments. It will be read with profit by anyone concerned with agricultural experimentation.—G.E.H.

BREEDING FIELD CROPS

J. M. Poehlman. Henry Holt: New York, 1959. 427 *pp.* (illus.) $8.50

This book is directed towards the needs of the ' undergraduate student in agronomy ' in North American universities. There are eighteen chapters of which the first five are general in content, containing brief reviews of ' the plant breeder and his work ', reproduction, cytogenetics, methods of plant breeding and techniques. The succeeding eleven chapters treat the eleven major annual seed-propagated crops of North America in some detail; the last two chapters are, respectively, devoted to the forage crops as a group and to seed production. The book ends with a glossary and an adequate

index. A curious omission from the list of major crops treated in detail is the potato which is surely a field crop within any reasonable definition of the term.

The approach throughout is practical rather than theoretical and the author brings a wide experience to bear on the subject. The result is a readable and informative text admirably adapted to its objective. It may be doubted, however, whether Chapters 2 and 3 are worth inclusion. The former is elementary botany which should be familiar to students; the latter attempts the impossible—a one-chapter review of cytogenetics—and, not unnaturally, fails. Better, this reviewer believes, to refer the student to independent texts, of which several good examples exist. In view of the audience to which the book is directed, the lack of theoretical (especially mathematical) treatment is perhaps inevitable but leading references to works in biometrical genetics and population theory could surely have been included. The bibliographies to individual crops (which are given at the ends of the relevant chapters) are long (often 70 to 80 items) and appear to be admirably complete; they will provide excellent sources for serious reading.

The book is splendidly printed in double columns and the layout of figures, tables and headings is most attractive. The photographs, which number more than 250, are mostly good and well chosen; the line drawings (more than 100, by Hannah T. Croasdale) are technically good but not always well conceived: for example, Fig. 2.8 is grossly over-simplified, even for a diagram; and the information given by Figs. 3.13–16 could surely have been offered more elegantly. Some of the drawings of floral mechanisms and breeding techniques are, by contrast, excellent (e.g. Figs. 15.7 and 17.5).

American plant breeding is, considered broadly, the most advanced in the world. This book gives a balanced and readable account of its achievement. The student in the tropics will find here comparatively little direct guidance in meeting tropical plant-breeding problems, for not only are the crops themselves different but so also are the agronomic and social circumstances and the pests and diseases. Nevertheless, Dr Poehlman has provided him with a useful review of methods of universal utility and a valuable collection of examples and references.—N.W.S.

THE GRAFTER'S HANDBOOK

R. J. Garner. Faber & Faber: London, 1958. 260 *pp.* (illus.) 25*s*

This standard work on grafting, budding and other methods of propagation has been brought up-to-date. Notable new features include descriptions of the double-shield budding technique to overcome incompatibility, the cotyledon-stage graft, growing-point graft and ways of handling delicate tissues. Extensions of the sections in the first book on the use of grafting to nurse shy-rooting cuttings, to curtail vigour and increase fruiting and to save trees by plant surgery have been made.

During the period since World War II and virtually since the first edition of this book, there has been a tremendous boost in the production of perennial tree crops in the tropics. Vegetative propagation in one form or another has enabled the selection of high yielding clones, so necessary for these crops.

New techniques of propagation have been evolved in cocoa, rubber, mango and nutmeg, amongst many other plants. The use of polythene in this connection has played a major part. The field, however, is still wide open, particularly in the minor fruit crops, for improvements to be made in technique and for cheapening current methods of production.

This book gives a first-class résumé of all known methods of vegetative propagation. It is one which will give to tropical agriculturists and horticulturists, professional or amateur, a clear and full understanding of underlying principles and guidance in technique. Its illustrations are excellent; it is easy to read and follow. What more can be said?—J.S.C.

OBITUARY

John Cecil May, C.M.G., O.B.E.

J. C. May, who died on 10 September 1959, worked for the Colonial territories of the British Commonwealth for forty five years. He went out to Nyasaland as an administrative officer in 1914. He went through the German East Africa campaign in the King's African Rifles, and lost an arm. Later he took part in the establishment of British administration in Tanganyika.

In October 1920 he was appointed Assistant Secretary to the Empire Cotton Growing Committee, and later to the Empire Cotton Growing Corporation. He served the Corporation successively as Assistant Secretary, Secretary, Executive Secretary and Director. From 1947 to his death he was a much-valued member of the Governing Body of the Imperial College of Tropical Agriculture, always ready to undertake difficult and unobtrusive work, such as that which he put into negotiating the existing pension scheme for College staff.

May played a large part in building up the very efficient administration of the Empire Cotton Growing Corporation, but it is not for administrative efficiency that he will be remembered. His real interest was in his men. Selecting candidates for studentships, setting up new recruits in their first posts, care of staff members and their families, and help and encouragement for them in their careers, were to him the really important things.

His interests were wide. He made it his business to know personally the men with whom his staff had to deal: Government officials, members of Legislative Councils, business men, planters and African farmers. To them all he offered an open-handed friendship that transcended business relationships, and contributed enormously to the success of the work under his charge.

One of his more important achievements was the negotiation of an agreement whereby the Corporation continued to be responsible for cotton breeding work in the Sudan after the establishment of the Republic. It is sad that his wisdom is no longer available to those who have to plan the maintenance of scientific services in Commonwealth countries that are becoming independent.

Recent Publications

THE IMPERIAL COLLEGE OF TROPICAL AGRICULTURE

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A Notebook of Tropical Agriculture. 6th ed. rev. and enl. 1957. 12*s* 6*d*

THE REGIONAL RESEARCH CENTRE OF THE BRITISH CARIBBEAN

Reports on Cacao Research—1945–51, 25*s*; 1952, 8*s*; 1953, 10*s* 6*d*; 1954, 12*s* 6*d*; 1955–56, 15*s*

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No. 5 British Guiana. The Mahdia Valley, The Bartica Triangle, The Kamarang and Kukui Valleys, A Part of the Upper Mazaruni Valley 1959, 14*s*

No. 6 British Guiana. The Rupununi Savannas (continued). The Intermediate Savannas. General Remarks. 1959, 15*s*.

OTHER PUBLICATIONS

Flora of Trinidad and Tobago. (The early parts were edited by the Department of Agriculture of Trinidad and Tobago but editing has now been taken over by the Botany Department of the Imperial College. The Flora may be obtained from either address.)

Volume 1—Ranunculaceae to Araliaceae (8 parts and index), 26*s* 6*d*

Volume II—Rubiaceae to Labiatae (6 parts to date), 23*s* 7½*d*

Further parts are in preparation

These and earlier publications can be obtained from the Library and Publications Department, Imperial College of Tropical Agriculture, Trinidad

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The following books written by members of the staff have recently been published:

Insect Life in the Tropics, by T. W. Kirkpatrick. Longmans, Green: London. 35*s*

Bananas, by N. W. Simmonds. Longmans, Green: London. 45*s*

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